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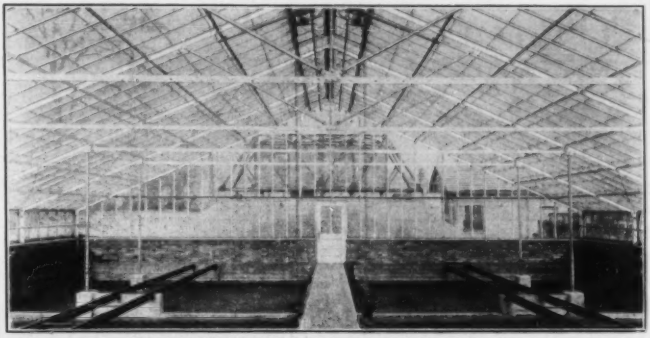

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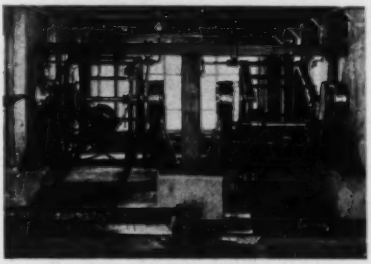

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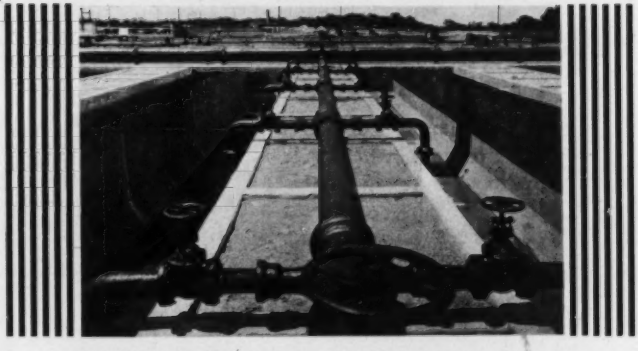

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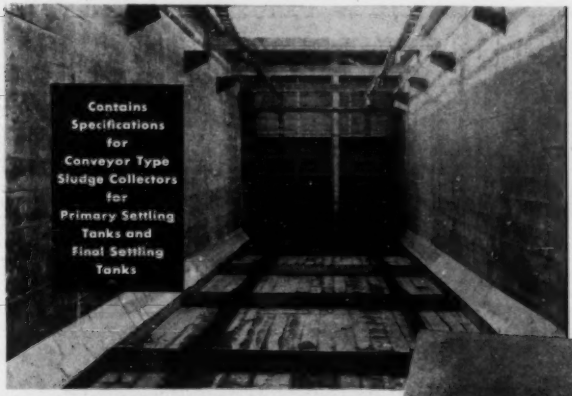

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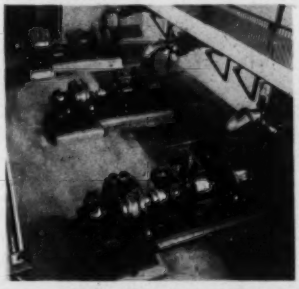

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Sewage Research

The Cardinal Points in the Art of Sludge Digestion—A Compressed Summary of a Quarter Century of Experience

By Dr. Hermann Bach*

In sewage disposal two entities are brought together in an appropriate action: the dead *substance* and the living *microörganism*.

The *substance* appears in the sewage in two physically different forms: the liquid portion (including the colloidally dispersed matter) and the insoluble (suspended) solids.

It is technically feasible to remove the suspended solids from the bulk of the liquid in a comparatively simple way; but to free the solids from the adherent liquid is not so simple. The deposited solids, called "sludge," retain water most tenaciously. Enormous energy is required to separate the water. Fortunately nature provides such energy in the smallest of living organisms. It is man's task to use this energy with reason.

Nature has provided specific bacteria for liquids and solids, each adapted to perform certain work. The "anaerobic" bacteria break up the solids by destroying the surfaces of the particles, which adhere so strongly to water; on the contrary, the "aerobic" bacteria act on soluble organic matter, first adsorbing the dissolved solids and finally being oxidized themselves.

It cannot be emphasized enough that the anaerobic bacteria are adapted only for the sludge, not for the liquid portion of the sewage. The aerobic bacteria are adjusted for the latter. Logically, sludge should be treated under anaerobic conditions, *i. e.*, in the digestion chamber, not under aerobic conditions. The liquid should be separated from the sludge as far as possible before being treated by oxidizing devices, whether trickling filters or activated sludge. Sludge particles have no function in the aeration chamber of an activated-sludge plant; the floc should be built up from the soluble and semi-soluble organic matter only, with the finely dispersed, unsettleable solids acting as anchoring points for the rising floc particles. The floc represents an aerobic conglomeration of microorganisms; this is a very exceptional status, indeed, for "sludge." As

* *Chief Chemist, Emschergenossenschaft, Essen, Germany.*

soon as its rôle in the aeration chamber is played out, the sludge should be immediately introduced into the digestion compartment, where it will be received and treated in an adequate manner by the anaerobic bacteria, specifically adapted to this task.

It should be kept in mind that all types of digestible material belong in the digestion chamber. Digestion is the most effective and the cheapest way to get rid of all nuisance connected with the disposal of sludge. No exception to this rule is necessary for activated sludge. The latter is, in reality, a very well digestible sludge, which should be allowed to digest as soon as its function in the aeration chamber is completed.

It is a common experience that the way to success is found through mistakes. The septic tank (Cameron) was a pioneer achievement because it consciously or unconsciously provided bacterial energy for the performance of work for which other available energies are quite insufficient. The mistake was only in the employment of one type of bacteria for sewage as a whole. With the separation of the sludge from the liquid (Travis, Imhoff) the decisive step was taken and progress in sewage purification practice occurred. Septicization for the sludge, oxidation for the sludge-freed liquid, is the logical procedure in the treatment of sewage. This simple dictum should not be violated by the mistake of filling the aeration chamber of an activated-sludge plant with raw or insufficiently clarified sewage.

What Happens in the Digestion Compartment?

The very complicated processes are as yet only partially understood. Among other well-known investigators the noteworthy work of the Dutch bacteriologist, Dr. J. Groenewege, should be mentioned, to whom we are indebted for a classical contribution to the study of sludge digestion.[1] The anaerobic bacteria, acting directly or by means of self-produced enzymes, break up the proteins into fatty acids or their salts, and split these latter compounds finally into methane and carbonic acid. A small amount of hydrogen is also liberated. The sludge bacteria unite all or part of this free hydrogen with the carbon dioxide, producing additional methane according to the equation:

$$4H_2 + CO_2 = CH_4 + 2H_2O$$

This is the reason why the ratio of methane to carbon dioxide in sludge gas is not constant. Whether the free nitrogen, present in varying amounts in all sludge gas, originates from the decomposition products of proteins or urea, or simply remains after exhaustion of oxygen from the dissolved air drawn into the digestion chamber with the sewage, is as yet not clearly elucidated. Probably it comes from both sources. With regard to hy-

drogen sulphide, this very objectionable compound is an unavoidable attendant of the anaerobic decomposition of albuminous substances and therefore also of sludge digestion. If the decomposition takes place in an alkaline medium, however, the H_2S combines with iron according to the equation:

$$H_2S + Fe(OH)_2 = FeS + 2H_2O$$

and remains in the sludge, blackening it. If hydrochloric acid is poured on a sample of digested sludge, the H_2S becomes liberated at once according to the equation:

$$FeS + 2HCl = FeCl_2 + H_2S$$

If sludge digestion is unsatisfactory and the sludge is acid, it smells badly, the H_2S being the chief source of the objectionable odor. When the proper methane fermentation occurs, accompanied by ammonia production and a slightly alkaline reaction (the bulk of the ammonia combining with carbon dioxide) the H_2S combines with iron and the objectionable odor ceases. This is the true explanation of odorless methane fermentation. It is not clearly understood, however, why ammonia production sufficient to overcome the acid reaction occurs contemporaneously with methane fermentation. Perhaps the ammonia is produced by the splitting action of bacteria on the decomposition products of albuminoid substances, resulting in production of the highly alkaline methylamine, CH_3NH_2, which may combine with hydrogen to form methane and ammonia according to the equation:

$$CH_3NH_2 + H_2 = CH_4 + NH_3$$

These considerations indicate that there are three sources of methane in the digestion chamber: the splitting action of bacteria on fatty acids and salts, the bacterial combination of hydrogen and carbonic acid, and the combining-splitting action on amines and hydrogen.

So long as the reaction of the sludge in the digestion chamber is acid, *i. e.*, before the bacteria have combined hydrogen with carbonic acid and amines, the sludge gas contains hydrogen in varying quantities. As soon as the reaction of the digesting sludge becomes alkaline, the hydrogen disappears from the gas or is reduced to a negligible amount.

As Dr. Buswell has pointed out,[2] the water content of the digestion chamber takes part in the formation of sludge gas, the water molecules entering the reaction which results in the splitting of fatty acids into methane and carbon dioxide. The formulae given by Dr. Buswell indicate that each fatty acid may become a methane-producer, although the lower acids play the most important rôle in the yield of sludge gas:

Acid	Equation
Formic	$4H.CO_2H - 2H_2O = CH_4 + 3CO_2$
Acetic	$CH_3.CO_2H = CH_4 + 3CO_2$
Propionic	$4C_2H_5.CO_2H + 2H_2O = 7CH_4 + 5CO_2$
n-Butyric	$2C_3H_7.CO_2H + 2H_2O = 5CH_4 + 3CO_2$
n-Valeric	$4CH_4H_9.CO_2H + 6H_2O = 3CH_4 + 3CO_2$
Lactic	$2C_2H_4.OH.CO_2H = 3CH_4 + 3CO_2$
and I may add:	
Malonic	$CH_2.2CO_2H = CH_4 + 2CO_2$

The conclusions of Dr. Buswell as to the yield of methane gas and the decomposition of protein and carbohydrates are of great importance.

Artificial Control of Alkalinity

Methane fermentation requires a pH of about 7.2 to 7.6. If the reaction of the sludge remains acid, it is possible to increase the pH value by the proper addition of lime. Such lime treatment has been carefully investigated and the working conditions prescribed by Dr. W. Rudolfs.[3] Although addition of lime may be easy in laboratory experiments or in a small-size working plant, it becomes quite difficult and annoying in a full-size separate-digestion plant, and is practically out of the question in a two-story plant. It is very difficult to keep milk of lime in uniform concentration and when it is mixed with the sludge the suspended lime particles become coated with the slimy colloidal matter, and further action is prevented. A vigorous and very intimate mixing of the milk of lime with the sludge is necessary before the sludge enters the digestion tank and even then there is risk of overcharging, paralyzing bacterial activity instead of promoting it. Normal digestion should proceed without the necessity for liming the sludge, leaving this measure only for exceptional cases.

In very obstinate cases, if methane fermentation does not occur and especially if the tanks are foaming, I would suggest the addition of an acetic salt, *e. g.*, calcium acetate, in order to develop and to strengthen the methane-producing bacteria.

Two-Story or Separate-Digestion Tanks?

In the work of a sewage treatment plant, sludge digestion comprises only a part of the whole task, although an important one. The design of a plant as a whole should not be restricted by preference for any special construction or type of plant. It is therefore an idle question to ask whether two-story tanks or separate-digestion chambers are more useful, as it is chiefly a matter of local conditions. It is necessary to have a clear understanding of the special advantages and disadvantages of the two systems in order to make a choice, in a given case, in accordance with the local conditions and requirements, always bearing in mind that in

this branch of engineering we are, as in many others, far from perfection.

The chief advantages of two-story tanks are: the small area required, the automatic and permanent removal of fresh sludge from the sedimentation to the digestion compartment, the absence of objectionable smell, the minimum of daily supervision, the effective insulation of the digestion compartment, and the reduced amount of power required to handle the sludge after it has been digested to a small volume. It is a great advantage that from the moment the objectionable solids enter the tank, they are not removed and are not exposed to the air and sight until changed through the digestion process to an inoffensive substance, quite different from the original material.

As disadvantages, may be mentioned the high construction costs in the case of unsatisfactory soil conditions, particularly if the ground-water level is high, an occasional inclination toward foaming, this being partly a function of the small surface area in comparison with the depth of the tank, the unsuitability for treating some sewages with high content of trade wastes, and sometimes ebullition of sludge particles from the digestion chamber into the sedimentation compartment, lessening accordingly the clarification effect. It must be emphasized, however, that skilled supervision makes it possible to avoid most of these operating difficulties, provided the sewage does not contain certain waste liquors totally unfit for treatment in such a plant. It seems, further, that it is more difficult to collect the sludge gas from a two-story tank than from a separate digester, although the calorific value of the two-story tank gas is, as a rule, higher than that of the separate-digester gas, owing to the smaller content of carbon dioxide in the former, this becoming washed out by the effluent.

The chief advantage of the separate-digester system is the flat construction of the sedimentation tanks as well as of the digester, reducing accordingly construction costs, particularly in the case of difficult soil conditions. A further advantage is the possibility of arrangement of mechanical sludge stirring devices and of chemical adjustment of the proper pH value, if such measure becomes necessary. Separate digesters can be artificially heated, two-story tanks cannot. It also seems to be possible, although at higher construction cost, to provide in separate tanks far more complete gas collection than in two-story tanks.

As disadvantages of separate digesters may be mentioned the necessity of close supervision, particularly as to the regular transfer of fresh sludge from the sedimentation tanks to the digester, the practical impossibility of completely removing all sludge from the sedimentation tanks, the need of considerable power for pumping fresh sludge to the separate digesters, and the somewhat lower calorific value of the gas in accordance with its higher CO_2 content.

The unprejudiced engineer will carefully consider the advantages and disadvantages of the two types of tanks in accordance with local conditions. It is of no value to lay stress on the recovery of a large amount of gas in the neighborhood of a rich source of natural gas and likewise it would not be of importance to provide insulation against cold in the tropics.

Artificial Heating

Although it is obvious that temperature control is one of the most important requirements in sludge digestion, it must be stated, however, that the technical means for heating digestion tanks of great size are as yet not satisfactorily developed. It is very difficult, without causing local superheating, to heat uniformly a large container filled with sludge which is a poor conductor of heat and likewise corrosive and viscous. While there are some promising attempts to raise the temperature of a separate digester by injection of hot water, or by passing the sludge outside the tank through a small tank equipped with hot-water coils, it must be emphasized that such methods are not altogether satisfactory.

Effective insulation must be considered as a part of heating. The especially good insulation in the case of Imhoff tanks can be nearly attained in the case of separate digesters by placing the walls of the sedimentation tanks adjacent to the digester (Prüss construction). Other insulating means are, *e. g.*, earthen walls, sludge jackets (proposed by the author), outboard drainage for cold ground water, and other types of construction.

Agitation (Stirring)

Sludge is agitated in order to fulfill various requirements. The usual acid reaction of the fresh sludge must be neutralized, simultaneously it should be seeded with the effective methane bacteria. Likewise the acid decomposition products of bacterial activity, including carbonic acid, must not be allowed to accumulate in parts of the sludge, but such gases and acids must be dispersed throughout the chamber, in order to become neutralized and to maintain a uniform pH value in all of the sludge. The methane bacteria cannot work in an acid medium created by their own secretions, and therefore these poisonous substances must be removed promptly. Further, it is desirable to prevent the formation of excessive scum on the surface and of deposits of thick sludge on the bottom of the tank, and last, but not least, it is desirable to disintegrate the coarser sludge particles into smaller aggregates with a greater specific surface. All these requirements are interlocking. Such processes occur to some degree automatically in every digestion chamber, but they are greatly promoted by mixing the upper layers with the bottom sludge by means of pumps or in other suitable simple ways, applicable both to two-story

tanks and to separate-digestion chambers. Far more effective, however, are mechanical stirring devices acting positively on all of the sludge contained in the chamber. Such stirring apparatus (*e. g.*, the Prüss screw pump) can be employed only in separate-digestion tanks because of constructional reasons and in order to avoid a lessening of clarification effect that would occur in two-story tanks.

In order to understand fully the importance of mechanical stirring of sludge it should be kept in mind that effective action of bacteria requires a very great amount of water. The limit of the lowest water content of sludge which will allow bacteria a full unrestricted digestive action is as yet not known accurately. It may vary with the composition of the sludge and with other factors. It may, however, be regarded as certain that the water content of digesting sludge should not be reduced to less than about 94 per cent if the digestion process is to take place under optimum conditions. Now it is very important that the available water be uniformly distributed through the whole mass of sludge, so that every particle of sludge material is surrounded by enough water to promote unlimited freedom of motion and action to the bacteria. This requirement is not quite satisfactorily fulfilled in unstirred sludge. For example, a sample of sludge drawn from a digestion chamber may show, if tested in the usual way, a water content of 95 per cent, this percentage being considered to be sufficient to maintain full bacterial activity. But such a sample may be composed of fine particles, with a water content of 97 per cent or more, and of coarser ones with a water content of only 85 per cent or less. These latter particles do not share so effectively in the digestion processes as the finer particles. The former must be disintegrated in order to be dispersed to finer solids, increasing in this way the moistened surface a thousandfold or more, and creating accordingly appropriate environment for bacterial action. A piece of fecal matter is able to maintain its shape a surprisingly long time in the digestion chamber, because its own water content is too low to promote digestion, which sets up at once, however, as soon as the mass becomes disintegrated. The finer the sludge particles, assuring uniform penetration of the available water through the contents of the chamber, the more propitious may be the prediction of effective digestion.

In considering the installation of a mechanical stirring apparatus for promotion of the sludge-digestion process, the designing engineer should naturally take care that the construction and working cost of such a device be in appropriate relation to the advantage expected by its use.

The Maintenance of Anaerobic Conditions

Since sludge digestion is an anaerobic process the digestion tank must be built and operated so that air will be excluded. A gas-tight cover is

essential. Stirring apparatus should always work under a cover, otherwise air may be sucked into the sludge. Likewise air should not be introduced when fresh sludge is pumped into the digester or when digested sludge is withdrawn.

The Limits of Digestion

Although it might be desirable to digest sludge until completely mineralized, complete mineralization is practically impossible. The degree of mineralization depends upon the content of organic matter, also the temperature, the technical devices employed and other factors. In general, the digestion of about 50 per cent of the organic matter is the practical maximum. The reduction of half of the total organic matter accomplishes an almost complete removal of objectionable material, a substantial decrease in sludge volume and a great improvement in the drying quality of the sludge. The digested sludge is freed from pathogenic bacteria, thus augmenting the usefulness of the substance as manure for agricultural purposes. Digestion provides a noteworthy income from gas utilization and lowers the costs for final disposal of sludge.

Thermophilic Digestion

This discussion is based, as noticed in the subtitle of this paper, on the developments of the past 25 years. Considerations of temperature refer only to normal conditions or to temperature increases of a few degrees. Now a new hope appears on the horizon, namely, the digestion of sludge at high temperatures, which would have been regarded as out of the question a few years ago. The importance of the achievement of Dr. W. Rudolfs and his chief collaborator, Dr. H. Heukelekian,[4] who have audaciously pointed out a new way to an old problem, cannot be overestimated, whether the laboratory results lead to practical application or not. To be sure, it is still a long way, and by no means a simple one, from the New Brunswick experiments to the employment of thermophilic digestion in large-scale plants. But where does any achievement in human culture or any progress in human technique occur without a long period of development? It is our duty to carry on and to try to reach the goal because *sludge is always with us.*[5]

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[4] W. Rudolfs and H. Heukelekian, "Thermophilic Digestion of Sewage Solids," *Ind. Eng. Chem.*, **22,** 96 (1930); **23,** 67 (1931); H. Heukelekian, "Further Studies on Thermophilic Digestion of Sewage Solids," SEWAGE WORKS JOURNAL, **2,** 219 (1929–30), and "Thermophilic Digestion of Daily Charges of Fresh Solids and Activated Sludge," *Ibid.*, **3,** 3 (1930–31).

[5] An editorial remark in *The Surveyor* some years ago but today equally apt.

Multi-Stage Sludge Digestion at Los Angeles County Sanitation Districts' Plant

BY A. M. RAWN*

During the fall months of 1929 experiments in separate sludge digestion were commenced at the Joint Disposal Plant of the Los Angeles County Sanitation Districts, the purpose of which was to determine what results in time, efficiency and economy might be obtained by exercising a careful control of digestion environment. The three experiments, results of which were utilized in the design and proposed operation of a sludge-digestion plant, are enumerated below in consecutive order:

Experiment No. 1.—For this work six one-gallon bottles were equipped for sludge digestion. Gas collection and measurement were accomplished by the usual method of measuring water displacement in a second bottle.

The procedure was to place sludge in the six bottles simultaneously in the following proportions:

Bottle Number	Per Cent Raw Sludge	Per Cent Seed Sludge	Per Cent of Supernatant Liquid from Digested Sludge Used as Seed
1	100	0	0
2	60	0	40
3	90	10	0
4	80	20	0
5	66⅔	33⅓	0
6	50	50	0

Daily observations were made of the six bottles for 35 days of each run. They indicated the following:

(*a*) Supernatant liquid from digested sludge, used for seeding purposes, had little if any effect upon the digestion time or efficiency.

(*b*) Digestion time was influenced by the amount of seed sludge added, decreasing as the proportion of seed sludge was increased.

(*c*) When the ratio of seed sludge to raw sludge was increased from one to four by volume to one to two by volume, the resulting benefit to digestion did not appear to warrant carrying such a heavy load of seed sludge.

(*d*) Volumetric ratio, of seed sludge to raw sludge, of one to four was sufficient to insure a pH value above 7 within three to five days and to maintain it throughout the digestion period.

(*e*) All foaming ceased abruptly when a pH value of 7 or above was reached.

Experiment No. 2.—The equipment for this experiment included a circular redwood tank, 22 ft. high and 7 ft. in diameter (see Figure 1), equipped with heating coils, a gas collection hood and meter, and a sludge

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circulating device which at intervals lifted digesting sludge from the tank bottom and spread it over the sludge surface. Valves were placed in the tank sides for sampling and the gas hood was equipped with a ship's port-hole for observation or sampling as required.

Sludge was introduced into the tank in the pre-determined ratio of four volumes of raw to one volume of seed or digested sludge and permitted to progress to satisfactory digestion, the measure of the latter being a fast drying, homogeneous mass, free from objectionable odor. Daily records were kept of temperature, gas production, hydrogen-ion concentration

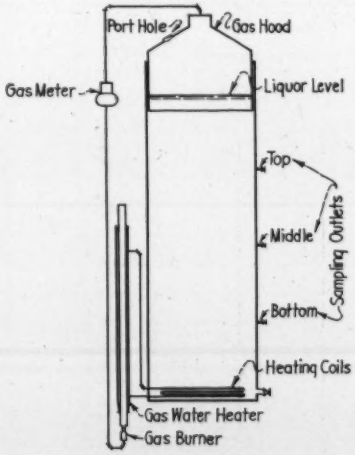

FIG. 1.—Schematic Sketch, 7′ Diam. × 22′ Redwood Tank.

and solids distribution as indicated by samples drawn from the "top," "middle" and "bottom" of the tank.

Results from this experiment are shown in the accompanying Figures 2, 3 and 4. They indicate the following for the described conditions:

(*a*) Rate of gas production and hydrogen-ion concentration are influenced by temperature, the more favorable conditions resulting from higher temperatures.

(*b*) Under optimum digestion conditions, gas production decreased rapidly after the 17th day.

(*c*) A vertical segregation of solids took place in the digesting mass with the higher proportion of volatile solids resting in the upper zone.

(*d*) The concentration of sclids in the bottom strata progressed with digestion.

(*e*) Foaming was prevalent while the pH index was less than 7.0 but ceased entirely and abruptly when it raised to 7.0 or above.

Experiment No. 3.—This experiment was conducted on a plant scale using two idle clarifiers and five idle aeration tanks as digestion chambers.

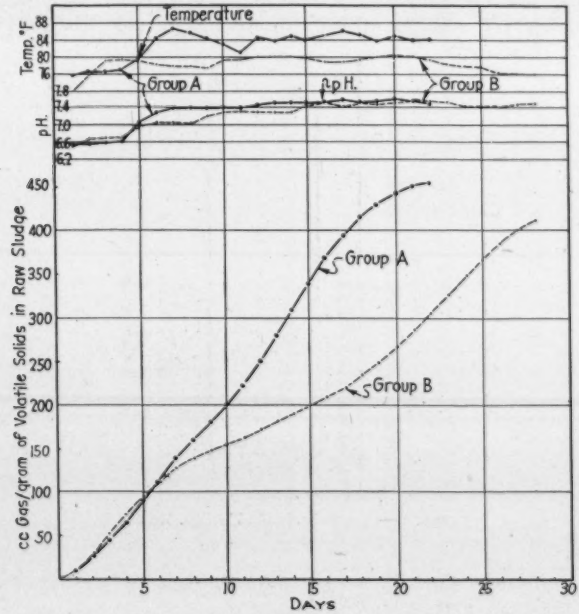

FIG. 2.—Temperature, Gas and pH Characteristics of Group A and B Experiments.

Raw sludge was pumped into one of the 35 ft. square clarifiers (I, Figure 5) where pH adjustment to 7+ was made originally by liming and later by addition of 20 per cent by volume of digested sludge. When Tank I was full, bottom sludge, equal in amount to the daily additions to Tank I, was withdrawn into Tank II. From Tank II (when full) bottom sludge was drawn into Tank III and in the same manner and condition bottom sludge

was drawn from Tank III to Tanks IV or IV-A. The procedure, prior to discharge to drying beds, was to fill Tank IV and permit the sludge to remain therein until Tank IV-A was nearly full, then to discharge Tank IV to the beds and refill, allowing IV-A to stand full until IV was nearly filled. Seed sludge was drawn from the tank next in turn for the beds.

This experiment extended over a period of eighteen months. The general results are indicated in Figure 6. The general characteristics of this work were as follows:

(*a*) The grease content was more concentrated in the first two tanks than in the raw sewage, indicating a retention therein of the lighter, more volatile material.

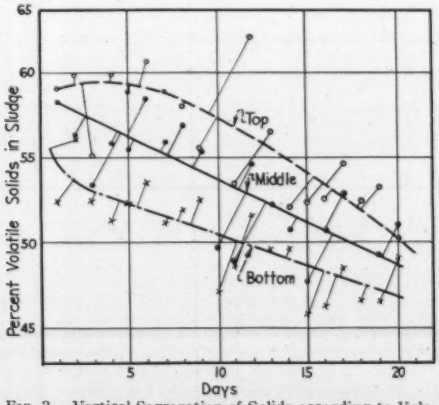

FIG. 3.—Vertical Segregation of Solids according to Volatile Solids Content, Group A Experiments.

(*b*) Gasification was most active in the initial stages.

(*c*) Seed sludge added to the initial stage in the volumetric ratio of one part seed to four parts of raw sludge raised the pH to above neutrality and maintained alkalinity throughout the process.

(*d*) Whenever the pH in Tank I dropped below 7.0, as it did occasionally in the colder months, foaming was prevalent in Tank I. Excessive foaming in Tank I could be induced by adding seed sludge greatly in excess of 20 per cent by volume.

(*e*) By introducing sludge from Tank I to Tank III (*i. e.*, by passing Tank II) excessive foaming could be induced in Tank III.

(*f*) Supernatant liquid of good quality could usually be drawn off when the volatile solids content dropped to 50 per cent or less. No supernatant liquid appeared in Tanks I and II.

(*g*) The lag in volatile solids indicated that a gravimetric segregation took place, with the heavier, more inert solids sinking to the bottom of the mass and progressing through the stages more rapidly than the average period of detention would indicate.

(*h*) Gasification appeared to be most active immediately following agitation or stirring of the contents of a tank.

(*i*) Without temperature control a well-digested, inodorous sludge, made up of raw primary clarifier and activated sludge, could be produced in from 20 to 35 days, varying in its organic solids content from 44 to 50 per cent.

Large-Scale Plant

Combining results of the three experiments it was concluded that multi-stage digestion, including gas collection and temperature and hydrogen-

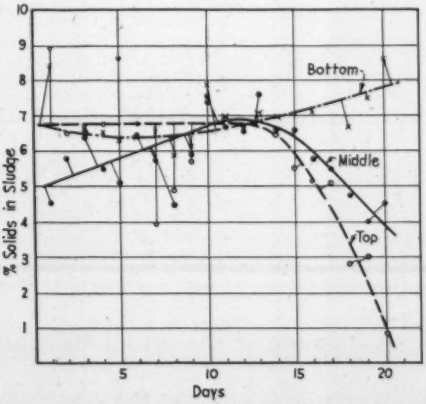

FIG. 4.—Total Solids Distribution, Group A Experiments.

ion concentration control, would best serve the purposes of the Districts in the disposal of sewage solids. Following is a description of the tanks erected and placed in service in July, 1931.

This installation (see Figure 7) includes two batteries, each 150 × 56 ft. in plan and averaging 16 ft. in effective sludge depth. Each battery is divided into four equal tanks and each tank in turn into three equal bays. The capacity of a battery is about 900,000 gallons, a tank 225,000 gallons, and each bay 56,250 gallons. The raw sludge capacity is 80 per cent in each case, the remaining space being occupied by circulating seed sludge.

By arranging the units so that the liquor level in each succeeding tank of

the four to a battery is three feet lower than the next preceding, sludge once pumped into the first or highest tank will flow through the entire battery to the sludge storage well, ready for transfer to the drying beds.

The system provides for raw sludge and seed to be introduced into the two outer bays of Tank I of a battery. Curtain walls divide the tanks longitudinally into three equal bays. These walls extend from the roof slab to within 12 inches of the floor. Thus, in order to reach the central bay of Tank I, solids must sink to the bottom in each of the outer bays and pass under the division wall. Gravimetric segregation therefore begins immediately and continues throughout the entire process as follows.

From a hopper located in the lower end of the central bay, sludge is delivered by gravity into the two outside bays of Tank II, through two diagonal riser pipes extending from within a foot of the hopper bottom, through the roof of Tank I, with discharge connections, at the prescribed

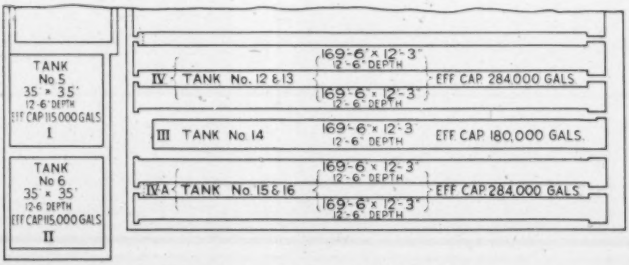
TANK No. 5 35' x 35' 12-6" DEPTH EFF CAP 115,000 GALS I
TANK No. 6 35' x 35' 12-6 DEPTH EFF CAP 115,000 GALS II
169-6" x 12-3" 12-6" DEPTH
IV TANK No. 12 & 13
EFF CAP 284,000 GALS
III TANK No. 14
EFF CAP 180,000 GALS.
IVA TANK No. 15 & 16

FIG. 5.—Experimental Series on Sludge Digestion.

sludge level in Tank I, extending into Tank II. Thus, the flow of sludge into Tank II is dependent upon the sludge level in TankI and no sludge will flow into Tank II until Tank I is at the requisite depth. This inter-tank discharge is arranged, similar to the curtain walls dividing a tank into bays, to advance only such sludge as may settle to the bottom of the mass, again taking advantage of what vertical separation may occur.

Tanks II, III and IV are exactly like Tank I except that, following experience with stage digestion experiments, less freeboard for foam or scum is provided than in Tank I.

From Tanks IV of both batteries sludge is discharged into a sludge storage well, the capacity of which is equal to that of one drying bed. One-third of the contents of the well will flow to the beds by gravity, the balance must be pumped. Seed sludge is taken from the storage well.

Tanks IV are equipped for supernatant liquid discharge—necessary

while digesting activated sludge but probably not essential when digesting thickened primary clarifier sludge alone.

The tanks are covered with a fixed concrete slab 8 inches in thickness. This top slab is fixed on columns and rests on a continuous wall bracket. Gas seal is provided by a copper flashing from slab to wall. The slab is free to move under temperature and load deformation without fracture. The roof is covered with a layer of asphaltum and 12 inches of earth.

Each of Tanks I, II and III is equipped with eight sludge circulating gas

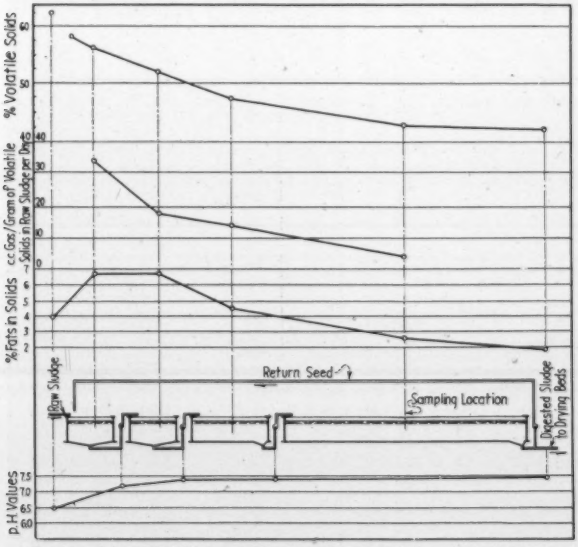

FIG. 6.—Schematic View and Digestion Characteristics of Multi-Stage Digestion Experiment.

lifts. They are designed upon the air-lift principle, using captured gas in place of air. These are designed to mix the contents of a tank as desired. Each tank is likewise equipped with sludge re-circulation piping so that sludge drawn from the bottom of a tank may be discharged back into the top or into another tank if desired. Any tank may be emptied—cut off from the gas collection and by-passed if desired. A sampling well is provided in each tank.

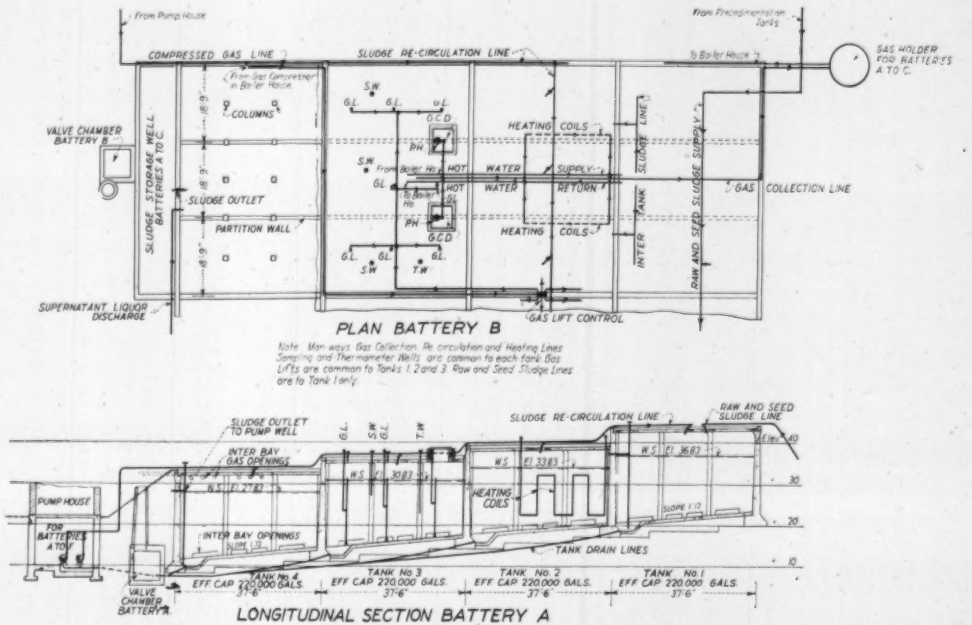
From Pump House
COMPRESSED GAS LINE
SLUDGE RE-CIRCULATION LINE
From Precipitation Tanks
To Boiler House
GAS HOLDER FOR BATTERIES A TO C
From Gas Converter in Boiler House
VALVE CHAMBER BATTERY B
SLUDGE STORAGE WELL BATTERIES A TO C
COLUMNS
SLUDGE OUTLET
PARTITION WALL
SUPERNATANT LIQUOR DISCHARGE
S.W.
G.L.
G.C.D.
P.H.
HEATING COILS
HOT WATER SUPPLY
HOT WATER RETURN
SLUDGE LINE
GAS COLLECTION LINE
INTER TANK
RAW AND SEED SLUDGE SUPPLY
T.W.
GAS LIFT CONTROL
PLAN BATTERY B
Note: Manways, Gas Collection, Re-circulation and Heating Lines, Sampling and Thermometer Wells are common to each Tank Gas Lifts are common to Tanks 1, 2 and 3. Raw and Seed Sludge Lines are to Tank 1 only.
SLUDGE OUTLET TO PUMP WELL
INTER BAY GAS OPENINGS
W.S. El. 3383
W.S. El. 3683
PUMP HOUSE
FOR BATTERIES A TO F
INTER BAY OPENINGS
SLOPE 1:12
TANK DRAIN LINES
RAW AND SEED SLUDGE LINE
Elev. 40
30
20
10
TANK No. 4 EFF CAP 220,000 GALS. 37'6"
TANK No. 3 EFF CAP 220,000 GALS. 37'6"
TANK No. 2 EFF CAP 220,000 GALS. 37'6"
TANK No. 1 EFF CAP 220,000 GALS. 37'6"
VALVE CHAMBER BATTERY A
LONGITUDINAL SECTION BATTERY A

FIG. 7.—Typical Plan of Sludge Digestion Tanks. G.L., Gas Lifts; S.W., Sampling Wells; T.W., Thermometer Wells; P.H., Portholes; G.C.D., Gas Collection Domes.

Sludge heating is accomplished with a hot water circulating system. Two-inch cast iron pipe coils are attached to the walls of each bay with the largest radiation surface in Tanks I. Water is heated in a 20-hp. vertical boiler using captured gas as fuel. The temperature of the water leaving the boiler is maintained at about 135° F., and returns at about 100° Fahrenheit. A 2-inch centrifugal pump circulates the heating water, the temperature of which is maintained within prescribed limits by a thermostatically operated, on-and-off gas control. Temperatures in each tank are shown at the boiler house by electrical indicating thermometers.

The batteries are plain and rectangular with full advantage taken of community walls. Battery B is constructed so that battery C may be connected to its outer longitudinal wall as desired. The tank floor slope—1 to 12—is based upon data published by John R. Downes in *Water Works and Sewerage*, July, 1930, as substantiated by observation at the plant. Bottom solids may be disturbed and mixed at any time by using the gas lifts or the sludge re-circulating piping.

Operating Results

The tanks were placed in operation in July, 1931, and were filled in sixteen days with primary clarifier sludge, activated sludge and digested or partially digested sludge drawn from the tanks used in Experiment No. 3. The first sludge discharged to the beds, seventeen days after starting operation, had an average moisture content of 93 per cent and an average volatile solids content of 49 per cent. The pH of all tanks was 7.5 or above and temperature within one degree of 85° Fahrenheit. Supernatant liquid from the sludge well showed a 5-day B. O. D. of 188 p. p. m., had a faint cooked odor and was slightly turbid. Continued operation during August showed supernatant liquid accumulating in Tanks II to IV of both batteries. This was promptly disposed of by emptying one Tank IV, then passing the contents of preceding tanks through Tank IV and drawing off supernatant liquid. A few days sufficed to empty all apparent supernatant liquid from the tanks.

During the hot days of August a great deal of trouble was experienced at the plant with the activated-sludge process, the sludge being in poor condition—very bulky and hard to concentrate. This condition resulted in a low solids concentration in the activated sludge pumped to the digesters and accounts for the accumulation of an abnormal amount of supernatant liquid. The condition has been remedied by re-settling the secondary clarifier concentrate with incoming raw sewage in a primary clarifier for a detention period of three hours.

Digestion results during August show average volatile solids in the digested sludge of 50 per cent or less, that the sludge is inodorous and dries to 60 per cent moisture within 14 days of discharge to the beds. As experi-

ence and skill in operating the tanks increases, it is likely that solids concentration in the digested sludge will be maintained at 10 per cent or slightly more, with resulting longer detention period in the digester tanks.

Gas pressure in the tanks is maintained at 11 inches of water, this being sufficient to raise the gas storage tank, flow through the oil flame traps and meters and operate the burners satisfactorily. Gas leakage from the tanks under 11 inches pressure is about 20 cu. ft. per minute. Production varies from 75,000 to 130,000 cu. ft. of gas per day, of which 10,000 cu. ft. per day are burned to operate the sludge-heating system. Sludge heating to desired temperature is being accomplished during the eight-hour day shift. During August the raw sludge temperature at the inlet to Tanks I averaged 77° Fahrenheit. No gas analyses have as yet been made.

Seed sludge is drawn from the sludge storage well three times daily and introduced into Tanks I, following which the contents of Tanks I are thoroughly mixed with the gas lifts. The gas lifts in each of Tanks II and III are operated once daily and it has been noted that following such operation the gas production increases appreciably for a short period. There are no stirring devices in Tanks IV, where supernatant liquid is drawn off prior to sludge delivery to the storage well.

A few months of operation under present conditions will doubtless disclose such weaknesses as the method may have and results should be interesting. The ease with which present operation is carried on, as well as results, so far, seem to indicate the soundness of the process. It is doubtful if the quantity of solids, up to the designed limit of the tanks, will have any pronounced effect upon the labor costs involved. At present one man working eight hours a day takes entire care of the tanks and beds and has ample time for planting and landscaping the area occupied by both batteries.

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Sewage Investigations at the University of Illinois*

BY HAROLD E. BABBITT**

An experimental plant for the study of problems in connection with sewage treatment has been operated by the Engineering Experiment Station at the University of Illinois since 1922. The plant is conveniently located in Urbana on the University campus and draws its sewage from the Champaign city outfall sewer, returning all sewage to the sewer after it has passed through the experimental plant. The plant is operated jointly by the Illinois State Water Survey and the Engineering Experiment Station but most of the tests are run independently by the two organizations. The present arrangement follows those investigations which resulted in the development, by A. N. Talbot, of America's first septic tank, and which were used by Edward Bartow in his pioneer investigations of the aeration of sewage and the activated-sludge process. At present the outstanding tests being conducted by the State Water Survey, under the direction of A. M. Buswell, include the digestion of corn-stalks with the production of methane, and the signal investigations which have been made on contact aeration. Results of tests made by the State Water Survey have been published from time to time, in periodical literature and in its technical bulletins. Most of the results of tests made by the Engineering Experiment Station staff on sewage have been reported in *Bulletin* **198** by H. E. Schlenz and myself.

Some of the more valuable results which have come from the work of the Engineering Experiment Station include: a laboratory test for the drainability of sludge; the effect of freezing on the drying of sludge; a method for converting an old Imhoff tank into a two-story separate-sludge-digestion tank; a formula for computing the rate of sedimentation of settleable particles in sewage; the effect of rain on the drying of sludge on drying beds; and, finally, the rate of gas production in Imhoff tanks. At present the investigations being made by the Engineering Experiment Station are confined to a study of the efficiency of various methods of producing activated slugde. The methods for which equipment is now installed include a Sheffield mechanical aerator, and a Vogt aerator of the type used, up to the present, only in water treatment plants. An air-diffusion unit is being designed and the installation of a small Simplex aerator is contemplated.

Freezing of Sludge

Imhoff tanks are usually designed today with the idea that no sludge will be discharged during the winter. The practice has grown out of the fact

* *Presented before the Fourth Annual Meeting of the Central States Sewage Works Association, Madison, Wisconsin, May 22, 1931.*

** *Professor of Sanitary Engineering.*

that the sludge will not digest so rapidly during cold weather and because it is considered that frozen sludge will not dry well on the drying beds.

Our findings concerning the beneficial effects of freezing on the drying of digested sludge preclude the necessity for holding the sludge for long periods in the compartments of Imhoff tanks until the advent of warm weather, but show it to be advantageous to discharge sludge on to the drying beds in cold weather so that it may freeze. From the observations made it is quite evident that freezing alters the draining qualities of sludge and allows the entrained water to separate very quickly after thawing, giving a much lower final moisture content in the sludge cake than is obtained without freezing during drying. The final sludge cake has characteristics well suited to its easy removal from the drying bed. The dried sludge has a spongy

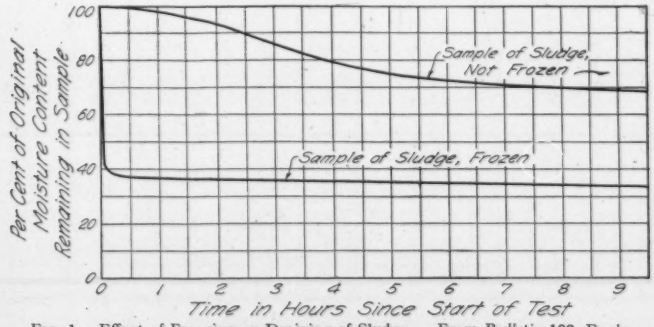

FIG. 1.—Effect of Freezing on Draining of Sludge. From *Bulletin* 198, Eng'g-Exp. Station, Univ. of Illinois

appearance, little cohesion, is easily pulverized, has no odor and separates easily from the sand on the bed. It would also be feasible to remove the sludge from the drying beds in cold weather while still in a frozen condition, to make room for the drawing of more sludge. The frozen sludge can be easily transported and allowed to thaw out and disintegrate at the point of final disposition.

The fact that the drying qualities of activated sludge are greatly improved by freezing opens a new avenue to the drying of sludge produced by this process. It was found that freezing and thawing of activated sludge so altered its characteristics that it would drain readily on sand beds. Some results of drainability tests on frozen and non-frozen activated sludges are illustrated in Figures 1 and 2. The beneficial effect of freezing on the rate of drying is strikingly shown in this graphic manner.

Drainability Tests

Standard Methods for Water Analysis, adopted by the American Public Health Association, do not contain a drainability test for sludge. In conducting our tests for sludge qualities it was necessary to devise some method for standardizing drainability tests so that results from different sludges could be compared. The usual experience of methods attempted but abandoned because of difficulties was repeated in our investigations, but success was finally attained through the following procedure: A volume of 615 cc. of standard Ottawa sand was heated to drive off all moisture and then cooled. The sand was placed in a sieve 8 inches in diameter, $2^1/_2$ inches deep, having 28 meshes to the inch in the sieve cloth. This volume of sand made a layer about $^3/_4$ inch deep on the bottom of the sieve. A one-liter sample of the sludge to be tested was placed on the sand, and the

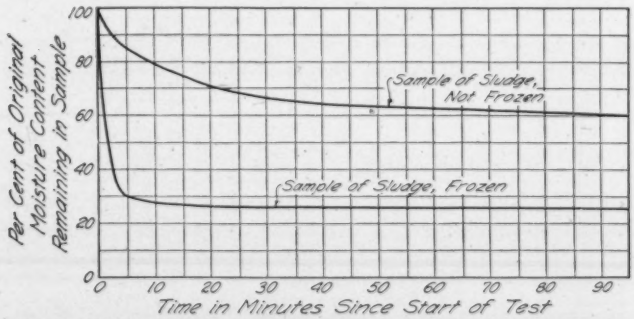

FIG. 2.—Effect of Freezing on Draining of Activated Sludge. From *Bulletin* **198**, Eng'g. Exp. Station, Univ. of Illinois.

amount of liquor drained off was noted at frequent intervals as it dropped through the sieve into a graduated container below. The sieve was covered during the procedure to lessen any error due to evaporation while draining. The percentage moisture content of the sample of sludge on the sieve was determined after draining had ceased and the total solids content of the drained liquor was determined for use in the computation of the quantity of moisture remaining in the sample at any time during the test. This latter determination was later discontinued as it was found that the content of solids in the drained liquor was negligible in making computations.

Results from this test were found to be highly satisfactory and duplicate tests on the same sludge gave identical results, indicating the close degree of precision with which results could be observed.

Sedimentation Formula

Sedimentation of settling particles has been a subject of study and research which has resulted in many formulae, theories and guesses. Most of these have been confined to the rate of settling of particles with a specific gravity appreciably greater than that of water, the materials most frequently tested having a specific gravity about that of quartz sand, *i. e.*, 2.65. In attempting to apply such formulae to rates of sedimentation in sewage settling basins it was found that they did not apply and that new studies were necessary. In making these studies it was attempted to hold constant all of the factors affecting rate of sedimentation with the exception of one of them: to control the variation of this one factor and to observe the effect on the rate of sedimentation.

Those factors which were considered to affect the rate of sedimentation include: (1) period of retention, (2) depth of flow, (3) size of particles, (4) specific gravity, (5) temperature, (6) electrical effects, (7) turbulence or character of flow and (8) the concentration of settling particles. It required nearly five years of study by different investigators to express the relation between all of these factors. The result was the following formula:

$$R = C\left[\frac{40}{50 - t}\right]\sqrt{\frac{[61 - d][D + 226]}{2.27[C + 40]\left[C + \frac{216 - D}{2.4}\right]}}$$

in which R = percentage of removal of settling solids
D = the retention period, in minutes
d = depth of tank, in feet
C = concentration of settling particles in the influent, in parts per million
t = average temperature in the sedimentation basin, in degrees Centigrade

It is to be noted that the formula contains no expression of the specific gravity, size of particles, electrical effects or turbulence of flow. It is assumed in the formula that the particles have a specific gravity only slightly greater than that of water, and that their diameters are so small as to approach those of colloidal particles. It is assumed that the flow of water is smooth, quiescent and continuous, and electrical phenomena have been neglected. The formula will hold for detention periods up to 120 minutes. Sedimentation which takes place after two hours is usually due to factors other than those normally connected with the subsidence of settling solids. A comparison of the results to be obtained by substitution in this formula with reported tests on sedimentation shows a remarkable and gratifying coincidence. The formula is entirely empirical and must, therefore, be used with the care necessary in the use of all empirical formulae, that is, it should be used only under conditions similar to the tests which resulted in its development.

In the tests it was found that for concentrations of settling matter below

about 150 parts per million the results of the determination of the percentage reduction of settling solids was quite erratic. This is probably due to the greater effect of uncontrollable factors when the concentration of settleable solids is relatively low.

The Drying of Moistened Sludge

To state that wet sludge will dry more rapidly than dry sludge sounds worse than a paradox; it has the sound of nonsense, yet in a series of tests with astonishing results, it was found that the moist sludge could be made to dry more rapidly by adding moisture to it. The conditions of the test simulated those conditions which are met by sludges on open drying beds in rainy weather.

The tests were conducted by preparing six drying beds each 12 inches square, all protected from rainfall and all placed together under identical conditions. Samples of sludge were taken from various tanks in the testing station and from sewage treatment plants of near-by cities. Each sample was divided into six equal portions, one portion of which was placed on each of the six drying beds. Every alternate day each bed was dosed with the same quantity of water which varied from nothing on one bed to one inch of water on the most heavily dosed bed. The water was sprinkled over the beds to simulate the action of rain. Daily observations of color, odor, general appearance, size of cracks and depth of sludge on the beds were made, and at the end of three weeks the percentage moisture content in the sludge on each bed was determined.

In every case, when the test was made on well-digested sludge, the beds which contained the sludges with the highest percentage of moisture were those which had been moistened but a moderate amount. The driest sludges were found on the bed which had received no moisture and on the bed which had received the greatest amount of wetting. In other words, the addition of water to some of the moist samples of sludge accelerated the drying of these moist samples. The practical significance of this test is that a heavy rain falling on open drying beds may accelerate the drying of the sludge rather than retard it. It also indicates that the protection of the drying sludge from rain by the use of glass covers may serve no useful purpose in hastening the drying of the sludge.

Such findings are apparently so far removed from probability and reason that some explanation is needed to assist belief. If a picture can be conceived of four or five particles of sludge forming an arch around a large void in the sludge, the void being filled with water, the hypothetical condition of particles in wet sludge can be imagined. If this sludge is allowed to rest undisturbed on a drying bed while evaporation occurs it can be imagined that each of the particles grows progressively smaller, due to loss of moisture in the particle, but the arched condition of the five particles persists and the

volume of the void filled with water remains relatively large compared with the volumes of the five sludge particles, thus maintaining a high percentage of moisture in the entire body of the drying sludge. Now if water be poured upon these partially dried particles of sludge they are lubricated and disturbed so that the particles slide over one another, the arch is broken, and the void between the particles and its contained water disappear. The sludge becomes more compact and contains a smaller percentage of moisture. The explanation might sound far-fetched were it not for the fact that the results satisfy the explanation.

Gas Production through Sludge Digestion

Unlike the paradoxical results obtained through the tests on the drying of moistened sludge, the results obtained from a study of gas production in Imhoff tanks is in accordance with the dictates of reason and with results found in similar tests by other investigators. It was found, for example, that the amount of gas produced increased with increasing accumulation of sludge in the tank. It was also found that the amount of gas produced increased with the temperature up to 24° C., which was the highest to which it was found possible to raise the temperature of the digestion compartment with the equipment available. The average quantity of gas obtained from Champaign city sewage, a typical domestic sewage from a residential community, was about 0.3 cu. ft. per capita per day. This would apparently warrant its collection and distribution as a public gas supply or for utilization as fuel in the production of light, heat or power around the treatment plant.

An attempt to increase the amount of gas produced in the Imhoff tank by heating the sludge in the digestion compartment proved to be impracticable because of the heat lost in the effluent from the tank. With the heating equipment available it was not possible to raise the temperature of the sludge-digestion compartment above 24° C. Under these circumstances the effluent was about 10 degrees warmer than the influent. Raising the temperature of the sewage 10 degrees requires about 150,000,000 B. t. u. per million gallons of sewage, if radiation and other losses are neglected. As this is far more than can be generated from the gas produced per million gallons of sewage, the heating of the digestion compartment of an Imhoff tank to produce gas from the sludge or to accelerate digestion, is concluded to be impracticable.

Heating a separate sludge-digestion tank proved successful and it was found that the optimum temperature for sludge digestion was in the neighborhood of 26° C., at which temperature gas production was nearly 2.5 times as rapid as at 17° C. It was calculated that on the basis of a separate sludge-digestion tank installation for a population of 10,000, a total heat value of 1,850,000 B. t. u. per 24 hours would be obtained from gas

produced at a digestion temperature of 17° C. If the temperature of the digestion tank were maintained at 26° C. it was calculated that a total of 3,010,000 B. t. u. would be generated, of which 710,000 would be required to maintain the temperature of the tank, leaving 2,300,000 B. t. u. available. This represents a net increase of 450,000 B. t. u. daily; the rate of sludge digestion would be increased, and less sludge storage space would be required.

Two-Stage, Two-Story, Separate Sludge-Digestion Tanks

Separate sludge digestion has been growing in popularity among sewage treatment plant designers within recent years and some two-story tanks have either been abandoned or turned into separate digestion tanks. In some plants it has been found advantageous to conduct sludge digestion in two stages, fresh sludge being drawn from a sedimentation tank and allowed to digest for a fixed period in a primary tank, after which supernatant liquid is drawn off and the sludge is pumped into a secondary digestion tank, where it is more completely digested.

One of the results of the tests made by the Engineering Experiment Station has been the design of a two-story separate sludge-digestion tank which is easily constructed from an old Imhoff tank and which has all of the advantages of two-stage digestion with automatic regulation of the sludge in the primary and secondary digestion compartments. The fresh sludge is discharged into the upper compartment of the two-stage digestion tank. Grease, scum and floating matter accumulate and digest in the primary compartment and settling matter falls through the slot into the secondary digestion compartment. Gases generated in the secondary digestion compartment are prevented from passing through the primary compartment to disturb sedimentation therein. With this arrangement there is a constant transfer of sludge from the primary to the secondary digestion compartment without the necessity for pumping or supervision; grease is excluded from the secondary compartment, and when sludge is added to the tank the supernatant liquid which is displaced contains a very small amount of settleable solids.

Since the material in the primary chamber passes into the secondary chamber as soon as it becomes partly digested only a small capacity is necessary for this chamber. The principal advantage, however, of the primary chamber is the prevention of entrance of grease into the secondary digestion compartment. Grease inhibits digestion and its retention in the primary compartment aids digestion in the secondary compartment. The amount of solids passing from the two-story digestion tank is small since the liquor displaced from the supernatant liquid is comparatively free from solids because of the quiescent sedimentation allowed. The liquor in the upper portion of the digestion compartment of a single-chamber, separate sludge-digestion tank in which gas is being generated is high in solids due to

the disturbance caused by rising gas bubbles. A patent has been applied for by the University of Illinois to cover this design as a protection to the public interest and to make it available, without royalty charge, to any designer or installing municipality.

Mechanical Aeration of Activated Sludge

Tests on mechanical aeration for activated sludge are now in progress so that no results of value are yet available. One surprising finding is the very short time in which activated sludge can be produced in raw sewage without seeding, by means of a Sheffield paddle aerator device. Sludge of fair quality has been produced without seeding the tank in a small per cent of the time which experimenters have found it necessary when diffused air is used. It has been found that satisfactory results can be obtained with relatively small power consumption, but the exact optimum relations between the various factors involved have not yet been discovered. Among the factors being studied are: period of retention, speed of revolution of paddle, depth of submergence of paddle, depth of tank, velocity of flow in the tank and details of tank construction.

The Vogt aerator operates on the principle of the Harris air compressor in that air is sucked into the sewage which passes through a narrow throat at a high velocity. The entrained air is carried downward in a pipe with the descending sewage and is then diffused quietly through the rising column of sewage as the direction of flow is reversed. Indications are that activated sludge can be made by the apparatus. Attention is being directed at present toward improving the economy and mechanical details of the apparatus so as to overcome some of the obvious and some of the possible difficulties.

Theoretical Relation between the Composition of Material and Its Mode of Decomposition

BY F. H. HESSELINK VAN SUCHTELEN*

From a theoretical standpoint it appears that a differentiation can be made between the two most important types of transformations caused by microörganisms—aerobic and anaerobic decomposition—on the basis of certain characteristics of the material acted upon.

These two types of decomposition are not fundamentally different. In nature we seldom see that one type of transformation alone is able to mineralize organic matter. It is only through a long sequence of aerobic and anaerobic transformations that the microörganisms are able to equalize the balance between synthesis and decomposition in nature.

A study of certain physico-chemical data indicates that the composition and properties of various substances may have a bearing on the type of decomposition. The different degrees of oxidation and the corresponding changes of properties of a few pure substances are shown in Table I.

TABLE I

OXYGEN CONTENT AND PHYSICAL PROPERTIES

	Formula	Oxygen Content %	Specific Gravity	Thermal Value per Grm. in Gcal.
Propane	C_3H_8	0	0.585	11,961
Propyl alcohol	$CH_3.CH_2.CH_2OH$	26.6	0.799	8,033
Propionic acid	$CH_3.CH_2.COOH$	43.1	0.987	4,959
Glycerol	$CH_2OH.CHOH.CH_2OH$	52.2	1.260	4,315

We note that:

1. Oxidized substances have a higher specific gravity than reduced materials.
2. Oxidized substances have a lower thermal value (per gr.) than reduced materials.

This is evident if one considers:

(*a*) The atomic volume and weight of oxygen.

(*b*) The addition of oxygen, resulting in partial combustion.

From a biological standpoint, the possibility of anaerobic decomposition (intramolecular oxidation) depends upon:

1. The amount of oxygen in the substance.
2. The position of the oxygen atoms in the substance.

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We know but little concerning the position of oxygen in the molecule. It is worth while, however, to consider whether the type of decomposition may depend upon the oxygen content and the related thermal values per gram of various pure substances.

In Table II many substances of physiological importance are described in terms of specific gravity, oxygen content and thermal value per gram, and at the same time their mode of generation and decomposition is indicated.

TABLE II

THERMAL VALUES OF DIFFERENT SUBSTANCES

		Specific Gravity	Per Cent Oxygen	Thermal Value per Grm. in Geal.
1.	Methane			13,175
2.	Ethane			12,280
3.	Propane	0.58		11,961
4.	Carnaubawax	0.99		10,091
5.	Benzene	0.88		10,038
6.	Paraffin oil	0.9		9,836
7.	Stearic acid	0.84	11.3	9,550
8.	Oleic acid	0.89		9,514
9.	Animal fat	0.93		9,500
10.	Palmitic acid	0.85		9,336
11.	Olive oil	0.91		9,328
12.	Myristic acid	0.86		9,133
13.	Japan and Myrica wax	0.97		8,990
14.	Amyl alcohol	0.82	18.2	8,947
15.	Lauric acid	0.86		8,844
16.	Undecylic acid			8,688
17.	Butyl alcohol	0.81	21.5	8,635
18.	Capric acid	0.89		8,634
19.	Propyl alcohol	0.80		8,033
20.	Heptyl alcohol	0.82		7,585
21.	Acetone	0.8		7,514
22.	Caproic acid	0.92		7,198
23.	Ethyl alcohol	0.79	34.8	7,130
24.	Valeric acid	0.94		6,686
25.	Azelaic acid			6,069
26.	Lignin	1.45		6,000
27.	Butyric acid	0.96		5,955
28.	Propylene glycol			5,670
29.	Suberic acid			5,650
30.	Crotonic acid	0.97		5,558
31.	Pimelic acid			5,420
32.	Methyl alcohol	0.78		5,341
33.	Propionic acid	0.99	43.2	4,970
34.	Adipic acid			4,582
35.	Ethylene glycol	1.12	51.6	4,543
36.	Glycerol	1.26	52.2	4,315
37.	Glycogen	1.45		4,187

TABLE II (*Concluded*)

	Specific Gravity	Per Cent Oxygen	Thermal Value per Grm. in Cal.
38. Cellulose	1.6		4,181
39. Starch	1.5		4,179
40. Dextrin			4,108
41. Sucrose	1.58		3,944
42. Glucose	1.54	53.3	3,735
43. Acetic acid	1.05		3,467
44. Succinic acid	1.56		3,020
45. Citric acid	1.5	58.3	2,478
46. Malic acid	1.6		2,400
47. Malonic acid			1,990
48. Tartaric acid	1.7	64.0	1,833

Substances Nos. 1 to 33 are reduced, lighter than water, generated anaerobically and decomposed aerobically.

Substances Nos. 34 to 48 are oxidized, heavier than water, generated aerobically and decomposed both aerobically and anaerobically.

Consideration of these substances indicates that the anaerobically generated substances, such as wax, paraffin, oil, fat, peat and wood are broken down predominantly in an aerobic way. Such substances possess a reduced oxygen content due to their mode of formation. Their relatively low density causes such substances to float at the surface of water, where oxygen is available, and an aerobic decomposition results.

Substances which owe their existence more definitely to aerobic conditions such as the oxygenated cellulose, starch and glucose, are susceptible primarily to anaerobic decomposition. After the oxygen in such compounds is reduced by biological action so that further transformation does not result in any gain in energy, the intramolecular transformations must cease. These materials and fermentation products may also rise to the surface of the liquid, where they are aerobically attacked and further broken down.

It seems that in nature the process of mineralization proceeds by both aerobic and anaerobic decomposition. In anaerobic transformations, the changed materials enter a new environment where they are easily oxidized.

The apparent exception to these generalizations is lignin. It is a substance with a relatively high thermal value and is accordingly aerobically attacked. Its high specific gravity, on the other hand, would indicate that the main line of attack was anaerobic. This exception might be explained by the fact that lignin is always accompanied in nature by elements of lower specific gravity.

The criteria of oxygen content, specific gravity and thermal value are, of course, not the only factors which determine the course of biochemical decomposition. The position of the oxygen in the molecules is of importance, also the oxidation reduction potential, and, above all, the physiological rôle

of the substance in regard to the microörganisms which effect its decomposition.

From these considerations we may conclude that:

1. In biological decomposition, the microörganisms are able to change the specific gravity of the material and the medium. By floating and sinking in a liquid medium, this permits alternate cycles of aerobic and anaerobic decomposition.

2. Aerobic decomposition yields products having a calorific value below 5.0 Kcal. per gram and an oxygen content higher than 45 per cent.

3. Anaerobic transformations are characterized by products which have a higher combustion value (per gr.) than the original material, these products being further decomposed only aerobically.

4. It seems possible to evaluate experimentally, on the basis of the calorific value (per gr.) of materials, whether:

(*a*) The humus was decomposed primarily by aerobic or anaerobic transformations.

(*b*) The course of decomposition took place in an unfavorable phase.

If the criteria discussed herein are found to be of value from a practical standpoint, it may be possible to control the environment so that the biochemical decomposition will take place in the proper phase, either aerobic or anaerobic.

Recent Trends in Sewage Treatment Methods*

BY EARNEST BOYCE**

Man, through his various changing modes of life since the beginning of history, has left a record of his attempts to solve problems of sanitation. Our earliest knowledge of man's attempt to govern his actions and those of his fellows by legal and moral codes is to be found in the Mosaic law and in that part of the law that might properly be called the first sanitary code, we find simple instructions for the disposal of human wastes. These rules were adequate for the simple life of that early civilization, and the fundamental principle expounded in those rules—that health could be safeguarded only by the disposal of human wastes in such manner as to prevent infection by contact—is still good public health doctrine.

As civilization advanced, the nomadic or roving habits of the earlier period did not permit the greatest development and comfort. The more permanent camps took on the form of towns or cities. People knew only the simple rules of sanitation that were adaptable to nomadic life and when congestion of population occurred, contacts increased and consequently, and correspondingly, the occurrence of infectious disease.

Following this era, history records the terrible lack of sanitation that marked that period of poorly organized government known as the Dark Ages. What little civilized man had learned of sanitation was lost, and plagues were endemic. Many of these plagues, we now know, were diseases that proper sanitation would definitely have controlled.

History is of more than passing interest to us. For it to be of value, we must avoid the mistakes that it records. History does not repeat itself unless the human race repeats its errors. History will not repeat itself if we recognize and apply in our modern civilization the more complete rules of sanitation that modern biological science has made available.

The civilization that we know is outstanding in the history of the world in the emphasis that is being given to problems of public health. We find but few among the nations of the world that give to sanitation the emphasis that it receives in this country. Because of this interest in sanitation, we realize that it is of prime importance to remove all sewage wastes from a city to a safe place for disposal. Modern sewers and the use of water to flush the wastes out of a city have made possible an important forward step in solving the problem of healthful living conditions in the congested areas of a city.

In this connection, it is of interest to quote from U. S. Geol. Survey *Water Supply Paper*, **185,** published in 1906:

* *Presented before Seventh Oklahoma Water and Sewage Short Course, Stillwater, April 23, 1931.*

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The disposal of waste is a fundamental problem for all living organisms. As the body takes in food and builds it up into its own peculiar structure, so it must continually break down and give off waste products, which, as a rule, if they accumulate, prove poisonous to the organism itself. This is the case with the individual; it is still more the case when large numbers of organisms are closely congregated together in communities. The political body resembles the organisms of which it is composed in no merely fanciful sense. It is subject to the laws of organic life; it has its income and its outgo; and a failure to remove the waste products of its life processes is inevitably dangerous to the units of which it is composed.

In spite of these facts, the attempt at scientific waste disposal is comparatively recent. The Cloaca Maxima and other so-called sewers of antiquity were rather drains than sewers, and their function was to lower the ground water level and not primarily to remove excretal wastes. Until 1815, the discharge of any waste but kitchen slops into the drains of London was prohibited by law, and the same regulation persisted in Paris up to 1880. Sewerage and sewage disposal proper really date from the epoch-making report of the Health of Towns Commission of Great Britain in 1844, which revealed the accumulation of an astonishing amount of decomposing organic matter and filth of all kinds in the cities.

Whereas in 1815 the sewers of London were simply drains to carry off the storm water—the discharge of sewage into them being forbidden by law—in 1847, only three years after the report of the Health of Towns Commission, it was made obligatory to discharge all sewage into those drains.

In other countries the example set in England was more or less promptly followed. In the United States, numerous drainage systems existed, one in Boston, for example, dating from the seventeenth century; but the first comprehensive sewerage project was designed by E. S. Chesbrough for the city of Chicago in 1855. On the continent of Europe, a sewer system was constructed at Hamburg after the great fire of 1842, by Lindley, an English engineer. Berlin installed sewerage in 1860 and other German systems quickly followed. France and the Latin countries, though still somewhat inadequately sewered, are making progress. No law of sanitation is now more clearly recognized than the principle that the wastes of human life must be diluted with an adequate supply of water and quickly removed from the region of habitation.

With the establishment of the water-carriage system, the difficulty was shifted from the individual to the community. The insanitary conditions surrounding the dwelling were relieved but at some point on the outskirts of the city the concentrated filth from its entire population must be disposed of.

It is proper that those charged with the responsibility of protecting health should have first concerned themselves with the problem presented by the city and that sanitary sewers should have been extended to give as complete service to a community as was possible. This greater need for the removal of sewage wastes from a city frequently made it necessary to appropriate the use of rivers and lakes into which might be discharged the wastes drained from the sewerage system of that city. As long as those receiving bodies of water were isolated and were not being used by others it may be presumed that the sewage wastes could be disposed of in that manner without danger. The safety of this method of sewage disposal, like that used by the early nomadic people, was dependent on the isolation of the place of disposal. The discharge of untreated sewage could be

tolerated so long as it served the sanitary needs of the city and at the same time did not create a health hazard elsewhere. Unfortunately, few cities were or are so situated that they can appropriate for their use a body of water for sewage disposal by dilution, without creating a condition adverse to the interests of others who may hold riparian claims to the body of water.

Because sanitary sewers are built where, for one reason or another, diluting water for disposal purposes is not available, the subject of satisfactory methods for sewage disposal has received a great deal of study during the past thirty years—with marked progress during that time.

In the discussion of sewage treatment, we perhaps should first try to define the purpose of the process before we discuss the methods by which the desired results are to be obtained.

We might define the effluent from a properly operating sewage treatment plant as one that may be discharged without cause for further concern on the part of those responsible for its production. Such an effluent would be the result of treatment adequate to remove the objectionable properties of the sewage to a degree sufficient to permit its discharge into the receiving body of water, without causing such water to become more dangerous to the public health, or to lose value or usefulness to the general public or to those whose riparian claims entitle them to special consideration. In case there is no dilution of the effluent by a receiving body of water, the sewage as discharged upon the surface of the ground must be in such condition as to prevent any cause for a health or nuisance complaint. It logically follows that the requirements for a good effluent vary widely with the local situation. Climate, topography, concentration of population, stream usage and many other factors are involved in determining just how far it is necessary to carry the purification process in a treatment plant—for example, where dilution may be available in a receiving body of water and local conditions may permit its use in the destruction of at least a portion of the objectionable properties of the sewage. However, whenever dilution is used as a final step in sewage treatment, we should recognize that the body of water in which this final treatment is taking place is being used and appropriated, by those responsible for the disposal of sewage wastes, as a part of the treatment works, and that the effluent of the treatment works must be such as will permit its satisfactory final disposal by dilution even under the most unfavorable condition of the receiving stream. Every city or industry using the public waters of the state for sewage disposal purposes must be regarded as being permitted to use those waters only to such extent as will not interfere with other higher usages. The use of public waters for sewage disposal purposes should not be considered an inherent right of any group, either industrial or municipal.

Most treatment plants are built and operated in order to accomplish

the quick removal or mineralization of objectionable organic matter contained in the sewage. They make it possible to control for greater effectiveness the forces that nature has provided for the destruction of organic matter no longer useful. They have been properly called bacterial workshops. The better the effluent expected the more careful must be the design of the workshop in order that it may accommodate itself to the variations that arise due to changes in the strength of the sewage wastes, temperature and other factors that are of great concern to the biological life upon which the success of the process depends. The effluent carries in solution the end results of this utilization of organic matter. If the conditions necessary for rather complete biological action have been provided, the effluent will contain as a result of this action, and in proportion to its completeness, only organic matter that can no longer support biological life involving oxidation processes. For the most part, the removal of the objectionable properties of sewage is accomplished by the biological oxidation of the organic matter present.

The amount of organic matter capable of further oxygen demand that may remain in an effluent and yet permit it to be called good, will depend largely on the limitations of the disposal or assimilating capacities of the receiving body of water. We must assume that eventually nature will insist on complete oxidation. The amount of oxygen available in the receiving body of water may be measured and the effect of varying degrees of depletion of this oxygen should be considered in determining the capacity of the receiving body of water for completing the oxidation processes.

This capacity will vary depending on a number of factors—principally volume, temperature and sources of oxygen depleting material other than of the effluent under consideration. For example, it is possible for aquatic plant growth to decay with such rapidity as to greatly deplete available oxygen. This condition is perhaps most pronounced when an ice cover on the receiving body of water prevents oxygen recovery by re-aeration and at the same time kills aquatic plant life. The periods of low flow in streams frequently occur during the summer when higher temperatures reduce to a minimum the available dissolved oxygen in the water, and at the same time increase the rate of bacterial activity and create a more rapid oxygen demand by the organic matter of the sewage. We should not consider the average condition of the stream and effluent, but rather the worst combination of effluent and stream condition that may reasonably be anticipated. If fish life is to be protected, an occasional depletion of oxygen in the receiving body of water will destroy the value of long periods of satisfactory results.

Thus far we have discussed only the biological oxygen demand of an effluent. There are other objectionable properties present in sewage wastes. First, we mention the presence of objectionable bacteria and,

second, the occurrence of rather stable organic or mineral chemical compounds that are inert to the biological changes that take place in a treatment plant.

Removal of bacteria in the average treatment plant is rather incidental to the oxidation processes. The importance of the quality of an effluent from this standpoint is again dependent on the nature and use being made of the body of water into which the effluent is being discharged. Proper cause for objection to the bacteriological nature of a sewage plant effluent should come from the possibility that the effluent contains pathogenic bacteria that may in some way complete the cycle of infection and cause disease. While effluents from various types of treatment plants may be expected to vary somewhat in their bacterial content, no effluent should be considered as safe from this standpoint until after it has been subjected to treatment specially designed to modify its bacterial content, preferably after the oxidation processes have been completed.

Fortunately, that group of bacterial flora most in evidence in sewage wastes and of most concern from the standpoint of possible disease causation from this source are quite easily destroyed by chlorine disinfection.

Because the danger from the bacterial content of an effluent is not so easily noticed as is a failure to oxidize properly the organic matter, the writer would suggest that this measurement of the requirements of a good effluent has not received the attention that it properly deserves from the public health standpoint.

The cycle of infection from sewage effluent has been quite effectively broken, but more by the introduction of other safeguards between the effluent and sources of water or food supply than by the complete treatment of the effluent. Whenever the receiving body of water is used directly in such manner as to give exposure by contact directly to persons, or indirectly to food sources, the sanitarian must judge carefully the dangers of bacterial pollution and set his bacteriological standard for a good effluent accordingly.

An effluent may be satisfactory as regards both biological oxygen balance and bacterial content and yet fail to be satisfactory due to the presence of stable organic or mineral compounds, usually the result of some industrial process. Fortunately the sources of these special wastes are definite and localized. This makes possible the present trend in design which is toward a special processing of these wastes at the plant where they are produced, so that the product can pass through the treatment plant and into the effluent in such a condition that it produces no objectionable condition in the receiving body of water.

If sewage is treated uniformly to such a degree that the effluent creates no problem or handicap to other uses of the receiving body of water, first, from the standpoint of an objectionable demand for further oxygen, second,

from the standpoint of a dangerous bacterial content and, third, from the standpoint of inert chemical compounds that have characteristics that make their presence in water a limiting factor in the use of such water, then it would seem that the essential requirements of a good effluent have been met.

With a definite conception of the characteristics that a satisfactory effluent must have and the biochemical processes and the controlling factors that must be satisfactory in order to secure proper results, we are in position to consider the design of the biochemical workshop—the sewage treatment plant. Having determined the standard of quality that the effluent must have, the engineer must develop his plant design so that the untreated sewage will be brought to the required standard by the time it passes through the plant. For this reason, no plant can be properly designed without first knowing the biochemical characteristics of the sewage to be treated, as well as the volume. One of the most interesting and most important trends in sewage treatment plant design is the realization on the part of the consulting engineer that sewage is not a simple compound having equal composition and volume for all cities, but that it may easily vary enough to cause assumed design data to be of little value. For example, a special investigation of a municipal sewage treatment plant designed for 20,000 population and actually serving 15,000 gave information that, due to certain industrial wastes, the biochemical oxygen demand on certain days was equal to an equivalent population of 44,000.

The engineer who keeps up with the recent trends in sewage treatment plant design will plan his plant so that it will, in the most economical manner possible, destroy the objectionable characteristics in the sewage. He will know the composition of the sewage for which the plant is being designed and how variations in composition will properly influence design capacities. His design will be rational in that it will represent the combination of all pertinent data regarding the particular problem under consideration, with the facts of operation as observed at other plants having similar characteristics, and the results of special investigations conducted by various interested agencies. Since the total of the information available from these sources is constantly increasing, it follows that the engineer must continually modify the basis of his design in order that the plants built under his supervision may give the best service possible.

An increased public interest in the elimination of pollution from our surface waters, not only from the health standpoint but also from the standpoint of the sportsman and those interested in a broad program of conservation, has resulted in increased technical study of proper treatment plant design. The work of chemists, bacteriologists, and others skilled in biological science is adding valuable information to the literature in this field. The engineer who does not recognize that his design must be in

keeping with findings of the biochemist is apt to find his design data obsolete.

Unfortunately, in this field as in others, not all recent trends can be accepted as being based on sound research. The desire to place on the market a device that will solve problems of existing design is a proper one and much good has resulted from research sponsored by interested manufacturers of special equipment. It would indeed be unfortunate, however, for the manufacturing industry as well as for the public, if the whole cost of special investigational work should be placed on those interested in the sale of special equipment, and the whole source of design data be from those who, by the very nature of their employment, are especially interested in the equipment of one manufacturer. There is need for more independent research study which should properly be sponsored and supported by the public who are to be benefited by the results of such study. The designing engineer should not accept all data furnished him for design and incorporate it into his plans without first coördinating this data with other sources of information. The engineer is by training qualified to evaluate the data before him and he works out the best design for each particular installation in accordance with his skill and judgment.

While it may be easier to convince a non-technical city official of the merit of some particular equipment than it is to present its design value to an engineer, this method of sale naturally results in handicapping the freedom of design on the part of the engineer and may logically result in a compromise in which the engineer accepts a design that may be inferior or more expensive for that particular installation. It is of particular interest to note that the greater amount of special equipment for use in sewage treatment has made possible a greater variation in design and has increased the possibility of more closely adapting a design to a particular situation. At no time in the past has the consulting engineer had as much opportunity to do such careful engineering work in sewage treatment as at present and, in like measure, at no time has the engineer been required to know so much about related biological and physical science as at present. Recent trends in sewage treatment have directed the thoughts of the engineer and his co-laborers in the field of biological science to an analytical study of more factors of design than were formerly considered. This combination of effort is bringing an answer to many difficult problems, especially in the disposal of troublesome trade wastes. With the advance now being made, we may properly be optimistic of the future and confidently predict that our surface waters will not become more seriously contaminated but rather that they will recover usefulness now lost, in some instances, due to uncontrolled pollution.

Sewage Works Operation

Digestion of Activated and Primary Sludge at Salinas, California

By T. R. Haseltine*

The disposal of the large volumes of excess sludge produced by the activated-sludge process has constituted one of the chief disadvantages of that method of sewage treatment. In 1922 Metcalf and Eddy[1] listed three methods of sludge disposal: drying on sand beds, lagooning and converting into commercial fertilizer. The first two methods leave much to be desired and the third is not economically feasible for small communities. The practice of digesting mixtures of activated and raw sludges has since become almost standard for small plants. In most of the early installations digestion was accomplished in Imhoff tanks. The increased popularity of the separate sludge-digestion system has resulted in the use of separate tanks in many recent plants. Data on the operation of these digesters are meager. This article describes the experiences and results obtained in the Salinas plant, the first of this type in California, and briefly compares them with those of a few other installations.

Salinas has a population of approximately 10,000 and an average daily sewage flow of 620,000 gallons. The monthly average flows are 16 per cent higher during the summer and 17 per cent lower during the winter, due in part to seasonal variations in population and in part to lowered groundwater levels during the winter. A typical analysis of the sewage is given in Table I.

Table I

Average of Eleven Daily Composite Samples Taken throughout the Year

Oxygen consumed	218 p. p. m.
5-Day B. O. D.	489 p. p. m.
Organic nitrogen	23 p. p. m.
Ammonia nitrogen	42 p. p. m.
Nitrate nitrogen	0.5 p. p. m.
Residue on evaporation	1364 p. p. m.
Loss on ignition of residue	651 p. p. m.
Suspended matter	361 p. p. m.
Volatile suspended matter	304 p. p. m.
Ether soluble	202 p. p. m.
Insoluble soaps	138 p. p. m.
Total grease	340 p. p. m.
Settleable solids	26 cc./liter

* *With Burns, McDonnell, Smith Engineering Co., 1031 So. Broadway, Los Angeles.*

pH	7.3
Alkalinity	332 p. p. m.
Chlorides	220 p. p. m.
Sulphates	111 p. p. m.
Magnesium	28 p. p. m.
Calcium	62 p. p. m.

Sludge Collection

Sedimentation. The crude sewage, after passing through a bar screen, is pumped to the primary settler. This tank, which is equipped with a Dorr traction-type mechanism for skimming and sludge removal, has an average theoretical detention period of 1.4 hours and an average settling rate of 900 gal. per sq. ft. per day at the present flow. However, a test was made in which dye passed from inlet to outlet in 10 minutes when the theoretical detention period was 50 minutes. In spite of this apparent short circuiting good removal of suspended solids is obtained as evidenced by Table II.

Prior to March the excess activated sludge had been pumped directly to the digester. This gave rise to several operating troubles. The piping was so changed that the activated sludge could be mixed with the crude sewage and resettled in the primary clarifier. During March to June, 1931, inclusive, activated sludge was wasted to the crude sewage at a rate of 23 gal. per min.; during July and August the rate was decreased to 14 gal. per min. and the length of time sludge was wasted was correspondingly increased. An average of 14,400 gal. per day was disposed of in this manner whenever sludge was wasted. Table II shows the reduction of suspended solids before and after the addition of the activated sludge to the crude sewage.

TABLE II

Month	Per Cent of Days Settler Rec. Act. Sludge	Monthly Averages of			
		Daily Flow, Gallons	Susp. Solids in Settler Influent, P. p. m.	Susp. Solids in Settler Effluent, P. p. m.	Percentage Removal of Susp. Solids
June, 1930	0.0	578,000	264	148	44.1
July	0.0	620,000	398	183	54.2
August	0.0	620,000	282	159	43.9
September	0.0	....	330	188	43.3
October	0.0	....	395	192	51.6
November	0.0	....	351	196	44.3
December	0.0	....	435	212	51.4
January, 1931	0.0	....	451	213	53.0
February	0.0	....	416	225	44.1
March	63.3	521,000	580	239	59.0
April	90.0	624,000	492	211	57.1
May	58.6	645,000	472	193	59.1
June	89.5	582,000	509	167	67.5
July	73.3	719,000	450	204	54.7

Sludge is drawn by gravity to a sump, from which it is pumped to the digester at a rate of 45 gal. per minute. The solid content of the primary sludge averages 6.0 per cent when no activated sludge is being wasted, as calculated from the difference in the suspended solid content of the raw and settled sewages and the volume of sludge drawn. The primary activated-sludge mixture averages 3.0 per cent solids when wasting activated sludge at the 23 gal. per min. rate, and 4.2 per cent solids when wasting at the 14 gal. per min. rate. Table III gives the characteristics of the two sludges as determined from occasional catch samples taken throughout the year.

TABLE III

ANALYSES OF CATCH SAMPLES OF GREEN SLUDGES

	Primary Sludge Only	Primary Activated-Sludge Mixture
Number of samples analyzed	24	14
Average specific gravity	1.006	0.998
Maximum solid content	14.3%	7.0%
Volatile content, average	70.2%	71.4%
Volatile content, range	53.4–75.1%	57.9–76.2%
pH, average	5.8	5.8
pH, range	5.4–6.4	5.4–6.4

Scum Collection.—As a result of the high grease content of the crude sewage a heavy, gray scum formed on the surface of the settler. It was necessary to operate the skimming mechanism almost continuously, and even then the surface of the sewage in the tank was unsightly. The mechanism removed a large amount of water with the scum. This material flowed to the sludge sump from which it was pumped to the digester—as much as 5000 gallons a day were pumped. To reduce this volume a scum concentration tank was built that receives all the discharge from the skimming mechanism. When it is full it is skimmed by hand; the skimmings go to the sludge sump as before, while the separated water is returned to the wet well of the pump station. By this means the volume of the scum has been reduced fully 95 per cent. Table IV gives an analysis of the scum.

TABLE IV

ANALYSIS OF PRIMARY SETTLER SCUM, DEC. 29, 1930

	Per Cent
Solids	21.8
Organic matter	84.6
Ether soluble matter	30.7
Vegetable fats	13.7
Mineral fats	17.0
Insoluble soaps	34.8
Total fats and soaps	65.5

Approximately 27 per cent of the total grease in the crude sewage was removed by skimming prior to the time when excess activated sludge was combined with the raw sewage. The addition of the activated sludge tends to prevent the formation of scum on the primary settler. Practically no scum is formed when wasting sludge at the 23 gal. per min. rate and only a comparatively small amount is formed when wasting at the 14 gal. per min. rate. Scum reappears shortly after wasting is stopped.

Sludge Digestion

The digester, shown in Figures 1 and 2, consists of a circular tank with four square hoppers in the bottom. The roof, which rests on eight columns placed around the interior circumference of the tank, is a concrete slab hung from steel beams encased in concrete. A wall around the perimeter of the slab extends above and below it. The roof is entirely free from the sup-

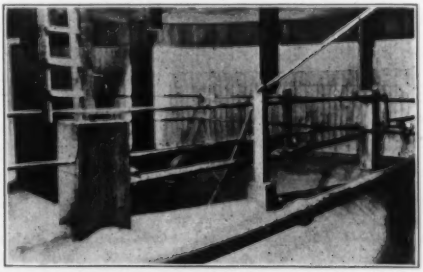

FIG. 1.—Interior of Salinas Digester Showing Inlet and Outlet Pipes, Heating Coils and Sludge Sampling Pipes.

porting columns and floats upon the sludge liquor when the tank is full. Its maximum rise is three feet. The digester is 55 ft. in diameter, and the maximum depth is 20 feet. The capacity is 34,100 cu. ft. or 3.41 cu. ft. per capita. Sludge enters through a 4-in. pipe riser in the center of the tank and is withdrawn through four 8-in. pipes, one of which originates in each hopper. Sludge may be drawn from the hoppers to the sludge sump and pumped back into the digester, thereby circulating its contents from bottom to top. A gas-collection dome is located in the center of the roof and all gas is metered. That which is not used in the laboratory or operator's dwelling is burned to control odors.

Sewage was first turned into the plant May 8, 1930; the digester was full June 6. On May 21, the pH at the bottom was 6.4. During the next thirteen days it dropped to 5.6 where it remained for fifteen days. It

reached 7.0 in eighty days, and the daily gas yield developed to 8000 cu. ft. in ninety-five days, after the tank was full. Haseltine[2] has described in detail the method of starting. Figure 3 shows the condition and performance of the digester since July 1, 1930, together with the quantity of activated sludge added. During the first seven months very little activated sludge was digested. Since then it has been wasted quite regularly; thus, an excellent opportunity to observe the effects of that material on digestion was afforded.

Scum Formation.—No scum was found on the digester until July 4, 1930, two days after the first activated sludge was wasted, when 0.5 ft. of brown, watery scum was found underlain by 9.5 ft. of relatively clear water. Seven days later the scum had disappeared. Since then it has been noticed that when the digester received activated sludge the scum

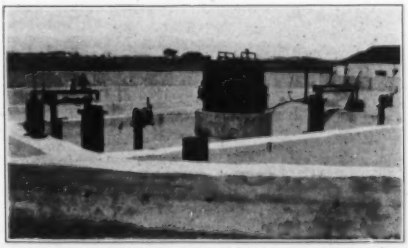

FIG. 2.—Floating Concrete Roof of Salinas Digester Showing Gas Collection Dome and Sludge Sampling Devices.

always formed and when no activated sludge was wasted the scum either disappeared or decreased in volume. The maximum depth of scum found was five feet; at such times there was no indication of a clear water zone. The scum was always the same color as the activated sludge. Up until early in June, 1931, it had an average solid content of 3.1 per cent and a volatile content of 64.7 per cent; the ranges being from 0.8 to 6.3 and from 56.4 to 74.4 per cent, respectively. The pH of this scum was always the same as that of the digester contents. On June 11 and 18, 1931, however, two feet of heavy scum was found underlain by three feet of the usual watery scum, beneath which was the sludge. This heavy scum contained 10 per cent solids, of which 70 per cent was volatile (on the dry basis). The pH was considerably higher than that of the lower material. The digester was undergoing a mild type of foaming at that time. It is probable that both the foaming and the heavy scum formation were caused by improper seeding ratios, as will be shown later.

At no time had there been any marked difference between the top and bottom sludges in the digester as indicated by pH, solid concentration or volatile content, consequently no sludge had been circulated. It was thought that circulation might decrease the scum formation, therefore from March 22 to May 6, 1931, 250 cu. ft. of sludge were drawn from each hopper daily and pumped to the top of the digester. This procedure apparently had no effect on the scum. Since May 6, 1931, the procedure has been as follows: fresh solids as they are drawn from the settler are stored in the

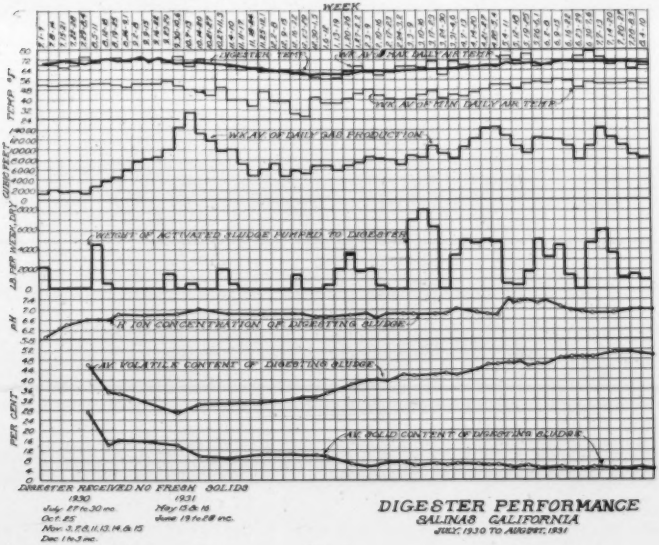

FIG. 3.

sludge sump until about 160 cu. ft. have accumulated, then an equal volume of sludge is drawn from one of the hoppers of the digester and introduced into the sludge sump at its bottom, so as to produce an intimate mixture of fresh and digested solids; the mixture is then pumped to the digester. It was hoped that the particles of activated sludge would become so thoroughly mixed with the other solids before their introduction into the digester that they would not separate to form a scum. This procedure proved to be of little value in combating scum formation but has been continued as a means of seeding the fresh solids.

Solids Concentration.—From the start it was noticed that whenever activated sludge was introduced into the digester the solid content of the digesting sludge decreased, and that the solid content increased again soon after the wasting of activated sludge was stopped. This condition is clearly shown in Figure 3. During January, 1931, when activated sludge was wasted more continuously than at any previous time, the density of the digesting sludge took the alarming drop of from 10 per cent to 5.5 per cent solids. The temperature of the sludge was then at a minimum and the low temperature may have been partially responsible for the drop in density, but inasmuch as the activated sludge with a solid content of from 1.0 to 0.5 per cent had been pumped directly into the digester, as much as 27,000 gallons being pumped in a single day, the drop in density was believed to be caused primarily by the addition of large volumes of liquor

FIG. 4.—General View of Salinas Plant from Top of Digester Showing Primary Settler in Immediate Foreground.

As a result of this experience arrangements were made to concentrate the activated sludge in the primary settler before introducing it into the digester. Since the completion of these arrangements, March 2, 1931, considerably larger amounts of activated sludge have been digested than previously and there has been no such marked decrease in solid content of the digester. However, the tendency for the density of the digesting material to drop with the addition of activated sludge and to increase when none is wasted is still well defined.

The increase in solids concentration of the sludge with depth in the digester has been small. The difference in solids content of the top and bottom sludges has ranged from nothing to 3.1 per cent; an average of all observations shows that the bottom sludge contained slightly less than one per cent more solids than did the top sludge.

Foaming and Supernatant Liquor.—As originally constructed the overflow liquor from the digester was returned to the inlet of the primary

settler below the water surface. Difficulties were encountered in establishing the activated-sludge process, so that in October, 1930, the supernatant liquor from the digester was diverted to one of the sludge beds because it was considered to be a possible source of trouble. From that time on, the character of the liquor could be observed and analyses were made after January 23, 1931. The average results from January 23 to August 7, 1931, inclusive, are given in Table V. It will be noted that up until March 6 the liquor was of fair quality although the suspended solids content was somewhat higher than that given by Kivell[3] for a well-operated digester. From March 6 to June 28 the solid content was much higher; the maximum suspended solid content during this period was 20,177 p. p. m. Large amounts of activated sludge were being digested during that period and it seems reasonable to believe that the increased solids content of the liquor was due either directly to the character of the solids, in the activated sludge, or to the increased ratio of the combined daily charges of fresh and activated solids to the amount of digesting sludge. During that period it was found that the solids content of the liquor could be kept down to some degree by drawing sludge frequently. Therefore, to avoid trouble with the clogging of the 4-in. overflow pipe, which was laid almost level for a few feet, an average of 3000 cu. ft. of sludge was drawn onto the drying beds every twelfth day.

TABLE V

AVERAGE ANALYSES OF DIGESTER OVERFLOW LIQUOR

Period, 1931	Dissolved Matter, P. p. m.	Suspended Matter, P. p. m.
Jan. 23 to March 5	1,594	1,286
March 6 to June 18	1,941	7,052
July 3 to July 31	2,194	23,518
Aug. 2 to Aug. 7	2,390	1,304

Early in June, 1931, the digester started foaming mildly for the first time since starting operation. Seeding ratios were investigated in an effort to determine the cause. It was found that from August 22 to December 30, 1930, the daily charge of fresh solids had averaged 0.7 per cent of the digesting sludge, calculated on a dry basis. During January, 1931, the ratio jumped to 1.1 per cent, due in part to the increase in amount of the daily charges, but primarily to the decrease in the amount of sludge that could be carried in the digester because of its decreased solid content and hence enlarged bulk. During February the ratio remained at 1.1 per cent, but jumped to 1.8 per cent in March, due to increased daily charges and the withdrawal of too much sludge. The further withdrawal of sludge during April and May resulted in a ratio of 2.6 per cent early in June. Apparently it was this high ratio that caused the foaming and the heavy scum formation that occurred at this time. Fortunately for the operators, a break in

the outfall sewer made it necessary to bypass the plant from June 19 to 29; during that time the foaming subsided. Since June 29 only 2500 cu. ft. of sludge have been drawn, no foaming has occurred and the amount of sludge has increased so that during the early part of August the seeding ratio was again 1.1 per cent.

During July, 1931, the digester overflow liquor had an extremely high solids content because so little sludge was drawn; the maximum suspended solids noted was 35,632 p. p. m. It was necessary to flush the overflow line several times a day. On August 2 the liquor suddenly started running of its own accord and has been of good quality since then. It is interesting to note that the suspended solids content of the liquor in the first part of August was practically the same as it was in February and that the seeding ratio for those two periods was the same.

Gasification.—The daily gas production was less than 2000 cu. ft. during May and June, 1930, while the sludge was acid. Early in July, 1930, the pH increased to 6.6; from then the gas yield increased steadily to a peak of 18,600 cu. ft. on October 8. That is the highest yield yet obtained and was probably due to the rapid digestion of the masses of organic matter that had accumulated and remained more or less dormant during the acid period. Since that time the two factors that have had predominating influences on the quantity of gas produced have been the temperature and the amount of fresh solids added; Figure 3 shows this clearly. The gas yield was low during November, 1930, due primarily to a marked decrease in amount of fresh solids added to the digester. Throughout the remainder of the winter the daily gas yield averaged 5000 cu ft. when no activated sludge was digested and 8000 cu. ft. when the digester received daily charges of that material; during the summer the corresponding yields were 8000 and 13,000 cu. ft., respectively. The difference between winter and summer yields is due primarily to the difference in temperatures; the averages were 61° and 71° F., respectively. The decreased sewage flow and hence decreased daily charges of both fresh and activated-sludge solids during the winter months was probably a contributing cause.

From the foregoing data it is apparent that the digestion of the excess activated sludge was responsible for a 40 to 60 per cent increase in gas production. Figure 3 shows no effect upon gas yield of variations in the pH of the digesting sludge from 6.7 to 7.3.

Table VI gives analyses of gas samples collected at different times, together with total gas yields, sludge temperature and pH, and information as to whether or not activated sludge had been introduced into the digester during the period immediately preceding the collection of the sample. Apparently the digestion of activated sludge resulted in the prevention of hydrogen sulphide production; decreasing the hydrogen-ion concentration apparently had the same effect but even at a pH of 7.2 there was a trace of

H_2S when no activated sludge was being digested. If the air and hydrogen sulphide contents are omitted from the analyses and the methane and carbon dioxide quantities correspondingly increased it will be seen that the digestion of activated sludge seemed to increase the production of carbon dioxide and to decrease the amount of methane produced; this effect was very pronounced at a pH of 6.8 but at a pH of 7.2 to 7.3 it was almost negligible. The analyses also show that decreasing the hydrogen-ion concentration results in decreased carbon dioxide formation and increased methane production.

TABLE VI

DIGESTER GAS ANALYSES

	Date of Collecting Sample, 1931			
	Feb. 28	April 30	May 22	June 2
Cu. ft. of gas produced	6856	14,224	8032	13,070
Activated sludge digested previously	No	Yes	No	Yes
Average pH of digester	6.8	6.8	7.2	7.3
Average temperature of digester, ° F.	62	66	68	68
Carbon dioxide, per cent	9.4	30.1	27.1	29.3
Methane, per cent	59.3	59.8	68.9	63.8
Nitrogen, per cent	4.4	4.1	4.0	4.4
Sulphur dioxide	None	Trace	None	None
Hydrogen sulphide, per cent	18.4	None	Trace	None
Air, per cent	8.5	6.0	7.0	2.5
Calculated B. t. u. per cu. ft.	723	603	624	645

The high power requirements of the activated-sludge process makes the utilization of gas for power production a much to be desired adjunct of sludge digestion. The influences of activated sludge and hydrogen-ion concentration on the character of the gas are very important in this connection, particularly their effects on hydrogen sulphide production because this gas, in appreciable quantities, is corrosive to valves and cylinder walls of an internal combustion engine. Unfortunately the Salinas laboratory is not equipped to make gas analyses and so the above conclusions have been drawn from rather meager data, but the tendency of activated-sludge digestion to reduce hydrogen sulphide formation has been checked with lead acetate paper several times.

Experiments are now being started with an automobile engine rebuilt to operate on gas; temporary means of heating the digester have been installed and runs will be made with and without temperature and pH control. After each run the engine will be inspected for corrosion.

Volatile Matter Reduction.—As shown in Figure 3, the volatile content of the digesting sludge decreased rapidly during July, August and September, 1930, at the same time that the gas yield was increasing. The volatile content reached a minimum of 26.9 per cent at the period of peak gas production early in October. During November and December it increased slightly to about 33 per cent, due probably to decreasing tempera-

ture and correspondingly retarded digestion processes. During January, 1931, it jumped to 40 per cent, due in part to the minimum temperatures prevailing at that time, and in part to the addition of larger amounts of activated sludge. The marked decrease in solid content of the digester during January, 1931, previously noted, resulted in a decided increase in volume of sludge to be digested. Only part of this increased volume could be cared for by carrying a higher sludge level in the digester, consequently a reduction in detention period in the digester resulted. The effect of this decreased digestion period is shown by the increasing volatile content of the sludge during the following months. The increased amounts of solids added and the unsatisfactory seeding ratios, which probably tended further to retard digestion processes, were also important factors in causing the increased volatile content. These factors were so predominant that in spite of the rise in temperature, with a corresponding increase in gas production, the volatile content of the digester continued to increase slightly in the spring of 1931. It has only been since July, 1931, that with decreased volume of daily charges due to higher solid content, decreased charges of activated sludge, continued high temperature and improved seeding ratios, the upward trend of the volatile content appears to be stopped. It is interesting to note that, as shown by Figure 3, the maximum and minimum gas production occurred a week later than maximum and minimum rates of wasting activated sludge during the months of January to May, 1931, inclusive, but since then the two have coincided.

The rise in volatile content of the digesting sludge indicates clearly the need of greater digestion capacity or a speeding up of the digestion processes. To increase the digestion capacity it would be necessary either to build another digester or to decrease the volume of the digesting sludge by increasing its solid content. We have not as yet been able to do the latter. As previously stated, the temperature of the digesting sludge averaged 61° F. during the winter and 71° F. in the summer. Data given by Rudolfs[4] and Fulweiler[9] show that if the temperature could be raised to 82° F. the time required for digestion would be reduced from 30 to 75 per cent. It is planned to heat the digester as soon as the most economical way of doing so can be determined. Coils for circulating hot water, for this purpose, were placed in the digester at the time it was built, but the best method of heating the water could not be determined at that time. The water might be heated in the conventional gas-fired boiler or the gas might be used in an internal combustion engine to generate power, the engine cooling water then being available to heat the digester. The ultimate method of heating to be used at Salinas depends upon the results of experiments now being started on the utilization of the gas for power production.

Sludge Disposal

Sludge drawn from the digester is run onto one or more of four drying beds. Each bed is 50 ft. by 62.5 ft. in plan. Sludge is introduced at the midpoint of one long side. The beds consist of 9 inches of sand underlain by varying depths of gravel through which open-joint tile drains are laid. Dry sludge is removed with forks and wheelbarrows.

In spite of the fact that in the fall of 1930 the volatile content of the sludge was reduced from 70 to 30 per cent, while this summer the reduction is only from 71 to 51 per cent, very little difference in drying times have been noted. This is probably due to the decreased solids content of the sludge now drawn. At no time has the sludge caused any odor or insect troubles. Table VII contains a few observations on the characteristics and drying times of different sludges. The surface of all sludges cracked within one to two days after drawing, unless it rained during that time.

TABLE VII

SLUDGE DRYING TIMES AND INFLUENCING FACTORS

Sludge Depth on Beds as Drawn, Inches	Solid Content of Sludge, Per Cent	Volatile Content of Sludge, Per Cent	Days Required to Dry	Rains and Elapsed Time on Beds before Exposure
9.0	15.6	30.8	10	None
9.6	4.6	51.2	9	None
10.5	5.8	46.4	14	Showers at 11 days
11.2	5.5	47.0	21	2 in. downpour at 8 days
11.6	5.3	46.0	15	Showers at 8 days
13.0	6.1	46.6	20	Heavy rain at 1 day and showers at 7 and 9 days

Most of the sludge produced has been used as fertilizer; much of it was used around the plant on lawns and shrubs; the Park Board has hauled a considerable portion into town for use in the parks; and a small amount has been sold to farmers for use in lettuce fields. An income of $180 was received from this last source the first year. It is hoped that as soon as the farmers become acquainted with the material a considerable portion of the sludge can be disposed of in this manner. At present the farmers pay about 17¢ a square yard for the sludge on the drying beds and remove it themselves.

Conclusions and Discussion

The first year's experience in the collection, digestion and disposal of fresh sewage solids and activated-sludge solids at Salinas has been given in some detail. In the following paragraphs the more important conclusions to be drawn from these experiences are stated and brief mention is made of similar experiences at other plants as extracted from current literature available to the writer.

The Editor[5] states that "the moisture content of sludge undergoing digestion is the most important factor affecting the cost of sludge-digestion tanks. The various factors that affect sludge digestion narrow down to the final consideration, from the standpoint of cost, of the capacity that must be provided to hold the sludge for the digestion period. This capacity is determined by the average moisture content." The Salinas experiences show that, once the capacity has been established, the moisture content of the sludge continues to have an important bearing upon the ease and success of operation. An increase in moisture content from 90 per cent to 94.5 per cent resulted in increased seeding ratios and a greatly reduced detention period for digestion, with consequent decrease in volatile matter reduction. The increased seeding ratios caused further decreases in volatile matter reduction, increased solid content of the supernatant liquor, heavy scum formation and ultimate foaming.

Rudolfs and Lacy[6] state that the concentration of the final sludge depends upon the density of the initial sludge and upon the time of storage. Experiences at Salinas, like those reported by Fischer[7] and Goudey,[8] show that when excess activated sludge as well as settled solids are being digested the density of the initial sludge can be greatly increased by wasting the excess activated sludge at very low, uniform rates to the inlets of the primary settlers. The rate of wasting has an important bearing on the degree of concentration. At Salinas it was found that when the rate of wasting sludge was 23 gal. per min., or 5.4 per cent of the average sewage flow, a total of 7740 gallons of combined sludge were pumped to the digester, as compared with 2400 gallons of primary sludge and 14,400 gallons of activated sludge that would have been pumped if no means of concentration were used, a reduction of 54 per cent; when the rate of wasting was reduced to 14 gal. per min., or 3.3 per cent of the sewage flow, the total amount of combined sludge was 4750 gal. per day, a reduction of 72 per cent. Goudey in a private communication to the writer states that at the Los Angeles reclamation plant the reduction in volume of sludge pumped to the digester by concentrating in this manner is 61.3 per cent when the rate of wasting activated sludge is 1.5 per cent of the sewage flow and 41.9 per cent when the rate of wasting is 15.0 per cent of the sewage flow. Decreasing the rate of wasting sludge from 23 to 14 gal. per min. did not affect the amount of suspended solids removed by sedimentation at Salinas. It is evident that to secure the maximum density of sludge the rate of wasting must be less than that necessary to prevent floc passing through the settler; in the writer's opinion it should be the lowest possible consistent with the disposal of the required amount of activated sludge. The addition of the excess activated sludge to the primary settler at Salinas has resulted in a higher percentage of suspended matter removed by sedimentation and decreased scum formation on the tank surface.

Salinas experiences show that the digestion of activated sludge results in the formation of a thin, watery scum, but that this scum causes no trouble. Although the practice of drawing sludge from the bottom of the digester, mixing it with the fresh solids and introducing the mixture at the top of the digester does not prevent scum formation it may be of some value in inoculating the incoming solids with the flora and fauna of proper digestion. Apparently this is not done at Los Angeles but Goudey[8] states that "the need of mixing excess activated sludge with the fresh sludge before pumping to the digester is apparent. In fact, even with disposal of excess activated sludge into the raw sewage, there is still need of sludge circulation from bottom to top (of the digester) to prevent stratification and to hasten digestion." On the other hand, Fischer[7] reports no scum at Salem when activated sludge is concentrated by combining it with the crude sewage.

The supernatant liquor from the digester is likely to have a higher solid content when activated sludge is being digested than when only fresh sewage solids are handled. At Salem[7] and Salinas the liquor contained 1100 and 1300 p. p. m. suspended solids, respectively, under the best conditions as compared with 600 to 800 p. p. m. for digesters receiving only fresh solids as given by Kivell.[3] Under adverse conditions the solids content may be very much higher. The Salinas experiences indicate that high seeding ratios result in high solids content of the supernatant liquor and vice versa. Fischer[7] attributes the reduction in solid content of the liquor at Salem to the concentration of the excess activated sludge by mixing it with the crude sewage, but it is noteworthy that that practice also resulted in increasing the solid content of the Salem digester and therefore the seeding ratio was reduced.

The average daily gas production at Salinas ranged from 0.5 to 0.8 cu. ft. per capita when no activated sludge was being digested, and from 0.8 to 1.3 when daily charges of that material were introduced into the digester, as the temperature ranged from 61° to 71° F. These yields are considerably higher than those reported by Fischer[7], Goudey,[8] Fulweiler,[9] Besselievre[10] or Zack and Edwards[11] although at many of the plants the temperature of digestion was controlled and higher than those obtained at Salinas. Heukelekian[12] concludes that the higher the fat content of the fresh sludge the greater will be the gas yield and Keefer and Kratz[13] in experiments on the digestion of scum from settling tanks found that the scum, which had a higher grease content than the sludge used as a control, gave higher gas yields than did the sludge. The Salinas sewage has an extremely high grease and fat content (340 p. p. m.); most of this is removed and introduced into the digester as scum, fresh sludge or activated sludge. It is possible that the digestion of this large amount of grease accounts for the high gas yields obtained.

The addition of activated sludge to the digester not only increased the total gas yield from 40 to 60 per cent, but, judging from a rather meager number of analyses, prevented the production of hydrogen sulphide, decreased methane production and increased carbon dioxide production. Current literature available contains very little information regarding the effect of activated-sludge digestion on the quality of the gas. Smith[14] states that aeration destroys by oxidation the sulphate splitting bacteria and so prevents the formation of hydrogen sulphide. "The effect of thorough aeration given sewage in the activated-sludge process of treatment seems to be carried over into the digestion tank. The resulting gases liberated in the digestion processes are entirely free from hydrogen sulphide."

Variations in pH of the digesting sludge from 6.7 to 7.3 apparently had no effect on the rate of gas production at Salinas, but it is possible, however, that the wide variations in gas production with varying temperatures and rates of addition of fresh solids masked the effects. Variations in pH, however, did affect the quality of the gas. Increasing the pH from 6.8 to 7.2 or 7.3 decreased hydrogen sulphide and carbon dioxide production and increased the methane content of the gas. This is in accordance with experience elsewhere. The tendency for activated-sludge digestion to increase carbon dioxide and decrease methane production was much less marked at the higher pH.

In considering any conclusions drawn from Salinas experience it must be remembered that the temperature of the digester was uncontrolled. Variations in temperature had marked effect on gas production and volatile matter reduction. It is possible that when the temperature of the sludge is raised to 80° F. all phases of digestion may undergo pronounced changes.

Salinas experience indicates that depth of sludge on drying beds and its solids content have a greater effect on the rate of drying than does the volatile content of the sludge. The effect of varying solids concentrations and depths of sludge correspond very closely to those reported by Downes.[15]

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Gas Collection from the Digestion of Activated Sludge at Rockville Centre, New York*

BY WESTON GAVETT**

A sewerage system and an activated-sludge treatment plant was designed for Rockville Centre in 1924 and the plan submitted to the voters. The project was badly defeated. The sewer committee persisted in an educational campaign and the project was again presented in 1929 and approved. The plant was re-designed to fit the new site but in general followed the original plan. In the 1924 report the following was stated:

> It is planned to let the plant help pay for the cost of operation, by utilizing the gas resulting from the digestion of the sludge. By so doing, several desirable results are accomplished:
>
> 1. The plant may be cut off the village line during times of peak load on the village system.
> 2. The power bill is reduced by the amount of power furnished by the gas.
> 3. The gas from the digestion process is all collected. As this might cause odor at times, if allowed to escape to the air, any danger of nuisance is removed.
> 4. A portion of the heat developed by the engine, ordinarily lost, is conserved by heating the sludge pumped to the digestion tanks. This will be of great value in the winter, as the bacterial action increases with the temperature.* * * * * * Obviously this gas is worth money, and is far too valuable to waste to the winds. Its cash value may be readily computed. One thousand cubic feet of gas per hour will supply 34 kw. or 34 kw. hr. In computing the cost of power used, we have used a value of $3^1/_2$ cents per kw. hr., the present rate. At this rate, 34 kw. hr. is worth $34 \times \$0.035$ or \$1.19. Thus 1000 cubic feet of gas is worth \$1.19, and 6000 cubic feet, \$7.14. This is the amount which the plant will pay toward its operation when the flow is 1.5 m. g. d. By the most conservative estimate, the power cost will be reduced 15 per cent by the use of gas. We expect that this figure will reach or exceed 25 per cent as our figures are based on data from plants where the utilization was a secondary consideration, whereas the Rockville Centre digestion tanks are designed not only for the digestion of sludge, but for efficient gas generators as well.

That the 1924 estimate was conservative is indicated by Mr. Kneale's estimate that more than half of the power cost is being saved by the use of methane gas.

In 1924 the power station, which is municipally owned, was operating to capacity and there was some question as to its ability to supply the power needed for the treatment works. It was therefore planned to install one large gas-engine-driven generator capable of carrying the entire plant load, so that this unit could be used during periods of peak load on the municipal plant. When the present plant was designed, however, the village had installed a new power plant of modern and efficient design, so

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** *Assistant Engineer, Clyde Potts, 30 Church St., New York, N. Y.*

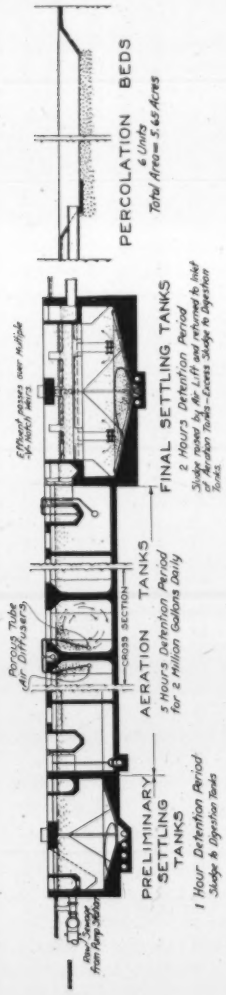
PERCOLATION BEDS
6 Units
Total Area = 5.65 Acres
FINAL SETTLING TANKS
2 Hours Detention Period
Sludge raised by Air Lift and returned to Inlet of Aeration Tanks—Excess Sludge to Digestion Tanks
AERATION TANKS
5 Hours Detention Period for 2 Million Gallons Daily
CROSS SECTION
PRELIMINARY SETTLING TANKS
1 Hour Detention Period
Sludge to Digestion Tanks
Perforated Tube Air Diffusers
Effluent passes over Multiple "V" Notch Weirs
Raw Sewage from Pump Station

FIG. 1.

that a change was made in the power equipment at the sewage treatment works. It was felt that one large engine would not be so desirable, particularly during the first period of operation, as two smaller units. A larger unit could be run for short periods only, when gas production was active. In the new design two gas engines were provided. One Buda four-cylinder $4 \times 5^1/_4$-inch gas engine was directly connected to a Connersville blower. This unit provides a most efficient use of the gas and is of value for obtaining a variation in the rate of air flow in the activated-sludge tanks. The speed may be varied to provide blower capacities of from about 400 to 800 cubic feet per minute. As the motor-driven blowers are of the direct displacement and therefore constant capacity type, this variable speed unit is of value. A second six-cylinder $4^1/_2 \times 6$-inch gas engine, operating at 1200 r. p. m. is direct connected to a 25 kv. a. generator. Both engines are equipped for either gasoline or methane gas operation.

The sewage treatment plant has been described elsewhere. ("Percolation Beds Provide Disposal of Sewage-Plant Effluent," by Clyde Potts, *Eng. News-Record*, April 23, 1931.) The plant was designed for a connected population of 20,000 of which about 13,000 are now tributary. At the design capacity the detention periods shown in Figure 1 are provided. At present the sewage flow is approximately 1.25 million gallons per day, as compared with the design flow of 2.0 m. g. d. The percolation beds were designed to treat activated-sludge effluent at the rate of 400,000 gallons per acre per day. The total cost of the plant was $483,000.

Sludge is obtained from the preliminary settling tanks, which precede aeration, and excess activated sludge is drawn by means

of air lifts from the final settling tanks. Sludge may be run directly to the digestion tanks by gravity but the operators have found it advisable to concentrate the sludge in a sump, where it is limed, and then pumped to the digestion tanks. Two pumps are provided for pumping sludge in the lower floor of the blower house, a Marlow diaphragm sludge pump of 167 g. p. m. capacity and a horizontal American sludge pump of 800 g. p. m. capacity.

There are eight units of sludge digestion tanks (Figure 2), each with a capacity of 7950 cubic feet, or a total capacity of 63,600 cubic feet. The water level in the digestion tank is maintained above the bottom of the roof by a weir on the overflow of the supernatant liquor pipe. This hydraulic grade is maintained constant but the level in the digestion tanks may be depressed as gas collects. The supernatant liquor discharges into the influent channel of the preliminary settling tanks and may be discharged at a low rate as gas pressure builds up. Sludge may be admitted through

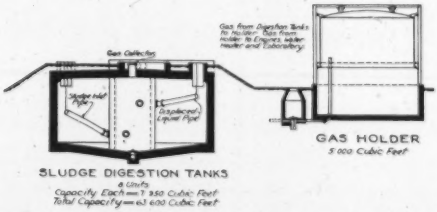

FIG. 2.

pipes above the sludge level or through the sludge outlet pipes at the bottoms of the tanks. The tanks are heated by hot-water heating coils with about 70 feet of $2\frac{1}{2}$-inch pipe in each unit. The water is circulated continuously by a 20 to 30 g. p. m. pump driven by a $\frac{1}{2}$ hp. motor. A small gas water heater and the water jackets and water-jacketed exhaust pipes of the engines are connected to the heating system. A constant level box is connected to maintain a constant level on the hot water system. Each digestion tank has a gas collector constructed of 18-inch flanged pipe. Gas is piped to a 5000 cu. ft. gas holder and thence to the gas engines, water heaters and laboratory. Digested sludge is dried on glass-covered sludge drying beds with total area of 20,720 square feet.

Plant operation was started in November, 1929. Sludge digestion proceeded slowly and it was not until July, 1930, that appreciable gas production was obtained. After the dormant period of the first winter, when the flow was increasing and sludge accumulating, lime was used to correct the reaction of the sludge. Gas production increased steadily until December,

1930, when the sludge temperature commenced to drop. Since the gas produced at that time was not sufficient to maintain the temperature which had previously been kept at about 70° F., an additional gas water heater was then installed with rating of 246,000 B. t. u. per hour. This was connected with a source of illuminating gas and more recently has also been connected with the sludge gas so that it may be run from either source. With this unit the temperature of the sludge was steadily raised and gas production has increased rapidly, until now about 13,000 cubic feet per day are being obtained.

The operators, Mr. John S. Kneale and Mr. George Anderson, have kept very complete records of temperatures, amount of sludge added to tanks and other operating data. The gas production dropped in Decem-

FIG. 3.—Earth-Covered Digestion Tanks and Greenhouse Type of Sludge-Drying Beds.

ber, 1930, when the sludge temperature dropped as low as 56° F., but a comparison of gas production and temperature of sludge does not indicate any striking relation. Of course the figures are complicated by several other factors such as the increasing load on the plant and the amount of sludge in the tanks. It would seem that the steadily increasing gas production was largely caused by the establishment of an almost continuous program of tank operation, the uniform addition of fresh solids and the frequent removal of digested solids.

The additions of solids to the digestion tank average 330 cu. ft. per day from the preliminary tanks, with 3 per cent solids and 1600 cu. ft. per day of excess activated sludge with about 1.2 per cent solid content.

Of particular interest is the need of preliminary sedimentation where activated sludge is to be digested. When the original plant was designed in

1924 preliminary sedimentation was not generally used and its inclusion in the plans was somewhat criticized. At that time it was planned to provide only one-half hour detention period. The preliminary tanks in the present plant were designed with a period of one hour. These tanks are removing about two-thirds of the settleable solids, since the sewage arrives at the plant from the pump stations with the suspended solids highly comminuted. Plans are being considered to improve the efficiency of these tanks. It is desirable to remove as much sludge as possible in the preliminary tanks, since it has less volume due to its higher percentage of solids. Excessive volume crowds the digestion tanks and greatly increases the amount of heat necessary to maintain the proper tank temperature.

The amount of heat required is made up of the heat to raise the added sludge to the proper temperature and the amount of heat to make up heat losses in the tanks. In January, when outside temperature was 23° to 40° F., one of the tanks was shut off, with no heat and no solids added or removed for 48 hours. The temperature dropped from 75° to 74° F. in this time. While this loss seems low it is actually very considerable.

During the winter months approximately 2,000,000 B. t. u. per day were required for raising added sludge to the required temperature and an equal amount for overcoming heat loss.

About half of the heat value of the gas is accounted for by heat utilized. In addition the gas was used for power.

The pH of sludge in digestion tanks has been kept at 7.0 to 8.0. About three tons of hydrated lime per month is used. The temperature range is 70° to 80° F. with the average above 70°.

The gas engines have operated very satisfactorily. They were started in operation about the first of August, 1930, and up to June 1, 1931, the engine-driven blower has been operated about 2800 hours and the generator 1460 hours. In this interval the engines were not taken down. About the first of June, one of the engines was examined and carbon removed. The operators are most careful in the oiling and care of the engines and report little difficulty, with the exception that spark plugs must be changed about every six weeks.

With the present yield of gas, it is not necessary to use illuminating gas. The records indicate that 20 to 30 cu. ft. of gas per hour per horsepower of work done is used by the gas engines. About 1.0 cu. ft. per capita is now being produced. With this amount the power available from gas is 15 to 20 horsepower per million gallons.

The cash value of the sludge gas is determined by the cost of power or fuel it replaces. Mr. Kneale estimates a saving of about $14.00 per day based on the actual reduction of power bills.

Compared to commercial gas at $1.00 per thousand cubic feet, and allowing for greater heat value, the gas is worth $13.00 per million gallons.

Taking electric power as a measure, and assuming 20 horsepower per million gallons produced by gas, the value of the gas per million gallons will be

$5.37 with power cost at $0.01½ per kw. hr.
7.16 with power cost at 0.02 per kw. hr.
10.74 with power cost at 0.03 per kw. hr.

These costs are based on fuel costs only and do not include interest and depreciation and maintenance. In most plants an alternate source of power is required for stand-by service, so the cost of engines is not chargeable to gas utilization.

Summary

Activated sludge mixed with sludge from preliminary tanks is being digested at Rockville Centre.

Gas produced has been used for power with good results since July, 1930. Gas production appears to improve as continuous addition of solids is approached with regular removal of digested sludge.

The courtesty of Mr. John S. Kneale, Superintendent of Sewers, and Mr. George Anderson, Plant Operator, in furnishing data on the operation is appreciated.

Operation of the Pre-Aeration Plant at Decatur, Illinois*

BY WILLIAM D. HATFIELD**

Introduction.—After two years of testing-station results[4,5] the pre-aeration unit for the Decatur plant was designed and constructed. The testing-station data had indicated that with a 2.5-hour aeration period from 30 to 40 per cent reduction in the 5-day oxygen demand of the settled sewage could be anticipated, and that the settled aerated effluent could be successfully applied to the sprinkling filters at three times the rate, in million gallons per acre per day, that could be used with the un-aerated sewage.

Since the Decatur plant was the pioneer plant of this type in America (following the lead of the Birmingham, England, plant) and since it treats a starch-waste sewage mixture, a summary of its operation should be of interest.

Historical.—The Decatur plant, consisting of grit chambers, coarse screens, Imhoff tanks, sprinkling filters and humus or secondary settling tanks, was placed in operation in the summer of 1924 (Figure 1). Due to a rapid industrial growth of the city during the design and construction period of the plant, the sewage from this city of 58,000 inhabitants had a population equivalent of 350,000. The Imhoff tanks removed an average of 22 per cent of the 5-day B. O. D., or 77,000 population equivalent. Experience showed that the sprinkling filters could be loaded[4,5] satisfactorily with 4500 pounds of B. O. D. per acre per 24 hours, a total of 13,500 pounds on the three acres of filters. This amounted to a population-equivalent loading of 26,500 per acre and about 80,000 for the three acres per 24 hours. A ninety per cent removal of this load was accomplished by the filters at these loadings. These operations were accompanied by most aggravating odors from all parts of the plant. The odors[6] from the screens, grit chamber, conduits and Imhoff tanks were successfully confined by coverings, gas collection and burning of the confined and collected odors, as well as the digestion gas, in an especially constructed oven.

With the Imhoff tanks and three acres of filters in operation, there remained about 200,000 population equivalent untreated. Extension of the sprinkling filters to 10 or 12 acres would have greatly increased the odor hazard from the filters and would have cost more than the Sanitary District could have financed by taxes and bonds. The pre-aeration testing station was built in January, 1925, and the present pre-aeration unit was completed and placed in operation in January, 1928, at a cost of $215,000.

* *Presented before Fourth Annual Meeting of the Central States Sewage Works Association, Madison, Wis., May 22, 1931.*

** *Superintendent, Decatur Illinois, Sewage Treatment Works.*

FIG. 1.—Decatur Sewage Treatment Works. Imhoff Tanks in Foreground, Pre-Aeration Tanks to the Left, Trickling Filters and Sludge Beds to the Right and Secondary Settling Tank in the Distance.

Description of Pre-Aeration Plant.—The pre-aeration plant[4] is a short period activated-sludge plant which is placed between the Imhoff tanks and the dosing tanks, the purpose of which is to reduce the B. O. D. in the influent to the filters and to modify it so that the rate on the sprinkling filters may be increased two- or threefold. There are six aeration tanks of the Manchester or spiral-flow type (Figure 2) which have a total dis-

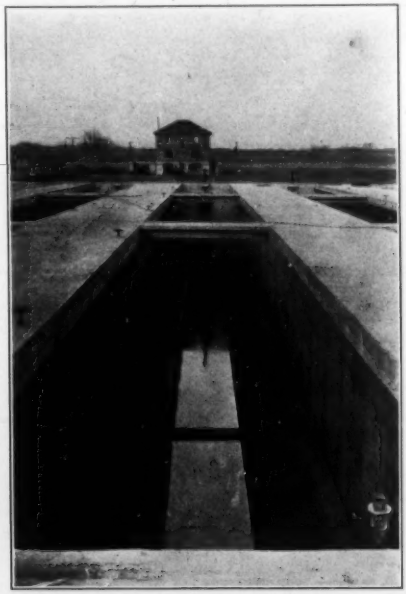

FIG. 2.—Spiral-Flow Aeration Tank at Decatur.

placement period of 2.5 hours at a sewage flow of 10 m. g. d. plus a sludge return of one m. g. d. The six tanks are arranged in three pairs for metering of the incoming sewage. The flow of air is also separately metered to the three pair of tanks and the conduits. There are two 77.5 ft. Dorr clarifiers for settling the aerated sewage, which have a total displacement period of 2.6 hours and a settling rate of 833 gal. per 24 hr. per sq. ft. of surface. The sludge is returned to the influent conduit without provision

for reaeration and to the influent to the Imhoff tanks for sedimentation and digestion with the primary sludge.

The designed and expected total capacity of the enlarged plant was 150,000 population equivalent with the following removals by the various units: 22 per cent, or 48,000 population equivalent, to be removed by the Imhoff tanks and 35 per cent, or 36,000, by the pre-aeration unit, thus leaving 66,000 population equivalent to be handled on the sprinkling filters and final sedimentation, which amounts to a loading of 22,000 population per acre of filters, which are 6 ft. deep.

Methods of Operation.—The plant has never ceased to be a large experimental plant, due to the unusual sewage received and the idiosyncrasies of under-aerated activated sludge[1-4]. Many experimental runs or periods have been made, but in general the operation may be divided into three groups which will be designated as (1) "Normal Aeration," (2) "Re-Aeration," and (3) "No Sludge Return."

"Normal Aeration" consists in operating the aeration plant in the way it was designed to run, *i. e.*, using all six aeration tanks to aerate the sewage and return sludge and obtaining an average displacement period of about 2.5 hours. The volume of sludge return has varied from 0.5 to 2.0 m. g. d. or from 5 to 20 per cent of the sewage flow. The total quantity of air has varied from 0.35 to 2.62 cubic feet per gallon of sewage aerated. In general, about 10 per cent of the air is used for aerating the conduits and 90 per cent in the aeration tanks proper. In most cases the air has been approximately 0.4 cu. ft. per gal.

"Re-Aeration" of the sludge is accomplished by utilizing the first two aeration tanks as sludge re-aeration tanks, and the remaining four aeration tanks for aeration of the mixture of sewage and re-aerated sludge. This method of operation reduces the time of sewage aeration to 66 per cent of that which would have obtained with the same sewage flow under the "normal aeration" method of operation, but allows for a sludge re-aeration period of from 4.5 to 22.0 hours, depending on the variation of sludge return from 2.0 to 0.41 m. g. d.

During most of the re-aeration periods the distribution of air to all tanks was equal so that the agitation was the same in the sewage and the re-aeration tanks. During a few periods experiments were made using mild and vigorous agitation in the aeration and re-aeration tanks, respectively, and vice versa.

"No Sludge Return" consists in operating the six aeration tanks similarly to the "normal aeration" plan except that no sludge from the Dorr clarifiers is pumped to the aeration tanks, but all the sludge is pumped back into the influent sewage just preceding the Imhoff tanks. There have been only a very few occasions when the Imhoff tank effluent has shown any signs of containing this aeration plant sludge. There may be some in-

oculation of the raw sewage with bacteria, protozoa and other materials which do not settle out in the Imhoff tanks, but this inoculation is not visible to the eye or under the low-power microscope.

This method gives slightly longer periods of aeration, because less sludge is pumped back to the Imhoff tanks than is kept in circulation with other methods of operation. In fact, the sludge is pumped back only intermittently and while it is quite dense.

The volume of air used has been about 0.4 cu. ft. per gal. of sewage and the air has been evenly distributed between the tanks except during May, 1931, when some special tests were run on different volumes of air to each pair of aeration tanks during aeration without sludge return.

The pre-aeration plant was started December 31, 1927, but the concentration of starch waste was not reduced until April 28, 1928. From January to May 1, 1928, only part of the sewage was treated by the aeration plant because the sewage still had a population equivalent of 350,000 and because we wished to create a good sludge if possible. Part of the time, in February and in April, the flow through the aeration tanks was nil and these periods (Nos. 4 and 8) have been eliminated from the data. From May 1, 1928, to date all the sewage (excluding excessive storm-water flow) has passed through the aeration tanks, except during June, 1929, when some experimental runs were made with lower sewage flows. During experimental runs like these the rest of the Imhoff effluent can be run directly on the sprinkling filters and mixed with the pre-aeration effluent in the dosing tanks. The population equivalent of the sewage in May, 1928, dropped to 130,000 and has gradually decreased since that time until now, with the industrial depression, it is about 80,000.

Microscopical examination of the filter effluent daily by Agersborg and Hatfield[1] in 1928 indicated that the filter sloughings contained the protozoan and metazoan life that seemed desirable and hard to maintain in the pre-aeration system. Therefore since July, 1929, the secondary settling tank sludge (humus) has been pumped back into the return lines of the pre-aeration sludge. This has increased the amount of sludge in circulation through the pre-aeration system, particularly during periods of re-aeration of the sludge.

The operation of the plant since January, 1928, has been divided into 64 periods varying from 5 to 31 days in length and averaging 20 days each. The early periods were so divided because of changes in operation which seemed necessary or desirable due to variable strength of sewage or condition of sludge. The later periods more nearly approach monthly periods.

Table I contains the operation data for the periods in chronological order, and Table II contains the same data rearranged into groups according to "Normal," "Re-Aeration" and "No Sludge Return" groups. For the sake

TABLE I

OPERATION DATA—PRE-AERATION PLANT AT DECATUR, ILLINOIS

Period	Month, Year	Days' Operation	Sewage Flow, M. g. d.	Sludge Return, M. g. d.	Sludge Return, %	To Digestion	Hours Sewage Aeration	Hours Sludge Re-Aeration	M.c.f. Air/24 Hrs. Re-Aera. Sewage	M.c.f. Air/24 Hrs. Re-Aera. Sludge	M.c.f. Air/24 Hrs. Total	C.f. Air/Gal. Sewage Re-Aera. Sewage	C.f. Air/Gal. Sewage Re-Aera. Sludge	C.f. Air/Gal. Sewage Total	B.O.D. P.p.m. Influent	B.O.D. % Removal	Susp. Matter Aeration Liquor, P. p. m
1	Jan., 1928	16	5.2	0.87	16.7	0	5.0	0	6.2	0	6.2	1.17	0	1.17	455	67	785
2	Jan.	10	6.2	0.90	14.5	0	3.88	0	5.9	0	5.9	0.95	0	0.95	400	44	480
3	Feb.	11	7.75	1.20	15.5	0	3.05	0	4.2	0	4.2	0.54	0	0.54	385	20	630
5	Feb.	10	2.76	0.61	22.1	0	8.0	0	4.71	0	4.71	1.71	0	1.71	405	78	1600
6	Mar.	11	3.49	0.32	9.2	0	7.2	0	5.9	0	5.9	1.69	0	1.69	360	70	370
7	Mar.	11	5.16	0.86	16.6	0	4.5	0	5.9	0	5.9	1.14	0	1.14	440	50	410
9	Apr.	6	2.22	1.1	49.5	0	8.3	0	5.82	0	5.82	2.62	0	2.62	360	92	895
10	Apr.	5	3.69	1.1	29.8	0	5.75	0	6.13	0	6.13	1.66	0	1.66	355	64	1550
11	Apr.	7	7.13	0.9	12.9	0	3.4	0	6.15	0	6.15	0.86	0	0.86	305	43	1300
15	June, 1928	11	4.78	0.7	14.6	0	5.0	0	4.60	0	4.60	0.96	0	0.96	260	56	180
35	June, 1929	10	4.48	0.92	20.5	0	3.30 (Exp'l.)	9.8	2.62	1.0	3.62	0.59	1.1	0.79	102	74.5	905
36	June	6	6.63	0.87	13.1	0	2.44 (Exp'l.)	10.4	2.09	1.0	3.09	0.32	1.2	0.47	108	69	910
37	June	18	8.60	0.83	9.6	0.11	1.92 (Exp'l.)	10.9	2.57	1.1	3.67	0.30	1.3	0.43	146	56	400

of brevity the data rearranged from Table I into Table II have been deleted from Table I.

Laboratory Control.—The crude sewage and effluents are sampled hourly at six points, *i. e.*, (1) crude sewage, (2) Imhoff effluent, (3) aeration tank effluent, (4) Dorr Clarifier effluent or settled aeration liquor, (5) sprinkling filter effluent and (6) secondary tank effluent. The data in Table III contain only samples (2), (3) and (4) because these are the ones that pertain to the discussion of pre-aeration.

There has been some slight change in the routine since 1928 but in general it has been and still is as follows: (1) Daily determinations are made of B. O. D., suspended matter and settleable matter on all samples; and dissolved oxygen, nitrates and stabilities on the sprinkling-filter effluent. (2) Total nitrogen, ammonia and oxygen consumed are determined weekly on weekly composites made up from the daily samples and preserved with sulphuric acid.

Interpretation of Laboratory Results.—In processes of sedimentation in Imhoff tanks, Dorr clarifiers and humus tanks, the removal of suspended and settleable matter is of foremost significance, but in such processes as pre-aeration, activated sludge and sprinkling filters the removal of B. O. D. is most important, and the removal of suspended matter is of secondary importance. The removal of suspended matter except in the pre-aeration process will usually be good if the B. O. D. removal is satisfactory. Dissolved oxygen, nitrates, stability and ammonia are, of course, very significant in the final or sprinkling-filter effluent but are not data from which quantitative removals or efficiencies can be calculated. They are not significant in the pre-aeration plant since the effluent usually does not contain dissolved oxygen, nitrates or stability and usually shows only one or two p. p. m. loss of ammonia nitrogen, if any.

The term population equivalent as used in the paper has been obtained by the following calculation:

$$\text{Population equivalent} = \text{p. p. m. 5 day B. O. D.} \times \text{m. g. d.} \times \frac{8.34}{0.17}$$
$$= \text{p. p. m. 5 day B. O. D.} \times \text{m. g. d.} \times 49.$$

Operating Results and Efficiencies.—The operation and B. O. D. data presented in Table I show the records of operation and the efficiencies of B. O. D. removal during the first eleven periods of preliminary operation before the starch waste was reduced, and represent "normal aeration" periods from 3.0 to 8.3 hours, with air applications from 0.54 to 2.62 cu. ft. per gal. of sewage aerated. The per cent removal of B. O. D. varied from 20 to 92, and increased with longer aeration periods and larger amounts of air. The influent sewage to the pre-aeration plant, during these first eleven periods varied from 305 to 455 p. p. m. B. O. D. with an aver-

TABLE II

NORMAL AERATION AT DECATUR SINCE MAY, 1928

Period	Month Year	Days' Operation	Sewage Flow, M. g. d.		Sludge Return, %	To Digestion	Hours Sewage Aeration	Hours Sludge Re-Aeration	M.c.f. Air/24 Hrs. Re-Aera. Sewage	M.c.f. Air/24 Hrs. Re-Aera. Sludge	M.c.f. Air/24 Hrs. Total	C.f. Air/Gal. Sewage Re-Aera. Sewage	C.f. Air/Gal. Sewage Re-Aera. Sludge	C.f. Air/Gal. Sewage Total	B.O.D. P.p.m., Influent	B.O.D. P.p.m., % Removal	Susp. Matter Aeration Liquor, P.p.m.
12	May, 1928	13	7.28	0.8	11.0	0	3.4	0	6.18	0	6.18	0.85	0	0.85	225	44	170
13	May	15	10.65	0.7	6.6	0	2.4	0	5.65	0	5.65	0.53	0	0.53	180	45	315
14	June	13	8.40	0.8	8.5	0	2.7	0	4.66	0	4.66	0.50	0	0.50	205	20	180
16	July	15	9.50	2.1	22.1	0	2.4	0	4.70	0	4.70	0.50	0	0.50	125	32	195
17	July	21	10.40	0.9	8.6	0	2.4	0	4.94	0	4.94	0.48	0	0.48	145	35	125
18	Aug.	13	7.12	1.1	15.4	0	3.3	0	4.81	0	4.81	0.68	0	0.68	130	38	195
19	Aug.	28	11.62	0.9	7.7	0	2.2	0	4.77	0	4.77	0.41	0	0.41	175	23	140
20																	
21	Sept.	31	10.36	0.4	3.9	0	2.6	0	4.65	0	4.65	0.45	0	0.45	125	36	160
22	Oct.	18	9.78	0.9	9.2	0	2.6	0	4.53	0	4.53	0.46	0	0.46	240	23	180
23	Nov.	6	9.06	1.4	15.5	0	2.6	0	4.50	0	4.50	0.50	0	0.50	300	10	425
39	Aug.	31	9.67	0.89	9.2	0	2.60	0	3.93	0	3.93	0.41	0	0.41	165	36	105
41	Oct.	30	9.92	0.39	3.9	0.50	2.55	0	4.10	0	4.10	0.41	0	0.41	132	37	105
43	Dec.	31	9.96	0.62	6.2	0	2.60	0	4.25	0	4.25	0.43	0	0.43	141	25	145
44	Jan., 1930	23	13.15	0.96	7.3	0	1.95	0	4.55	0	4.55	0.35	0	0.35	119	35	180
45	Feb.	18	11.60	0.65	5.6	?	2.24	0	4.48	0	4.48	0.39	0	0.39	160	25	120
53	Aug.	14	9.16	0.53	5.8	0.19	1.85 (4 tanks)	0	3.46	0	3.46	0.38	0	0.38	105	35	225
56	Sept.	25	9.56	0.56	5.9	0.22	2.66	0	4.02	0	4.02	0.42	0	0.42	106	43	260
Average		**20**	**9.83**	**0.86**	**9.0**	**0.05**	**2.54**	**0**	**4.43**	**0**	**4.43**	**0.48**	**0**	**0.48**	**163**	**32**	**190**

RE-AERATION

24	Nov., 1928	15	9.35	0.5	5.4	0	1.68	18.1	3.03	1.5	4.53	0.32	3.0	0.49	285	19	155
25	Dec.	11	7.78	0.5	6.4	0	2.21	18.1	3.70	0.4	4.10	0.48	0.8	0.53	280	18	170
26	Dec.	15	9.65	1.0	10.4	0	1.72	9.0	2.14	1.2	3.34	0.22	1.2	0.35	175	14	148
32	Apr.	25	14.10	1.0	7.1	0	1.21	9.0	2.93	1.0	3.93	0.21	1.0	0.28	117	25	530
33	May	19	14.35	1.0	7.0	0	1.19	9.0	2.62	1.2	3.82	0.18	1.2	0.27	118	33	385
34	May	15	9.16	0.94	10.2	0.06	1.80	9.6	2.79	1.0	3.79	0.30	1.1	0.41	121	45	695
38	July	27	10.65	0.68	6.4	0.10	1.60	13.3	2.65	0.9	3.55	0.25	1.3	0.33	129	36	230
48	Mar., 1930	21	11.30	0.44	3.9	0.15	1.54	20.6	3.33	1.6	4.93	0.30	3.6	0.44	85	28	180
49	Apr.	30	12.60	0.48	3.8	0.12	1.39	18.8	3.30	1.3	4.60	0.26	2.7	0.37	90	22	157
50	May	31	11.80	0.53	4.5	0.09	1.48	17.1	2.80	1.4	4.20	0.24	2.6	0.36	99	27	165
51	June	30	10.40	0.63	6.1	0.06	1.65	14.4	2.80	1.4	4.20	0.27	2.2	0.40	90	25	220
52	July	31	9.54	0.63	6.6	0.15	1.77	14.4	3.03	1.1	4.13	0.32	1.8	0.43	98	41	183
57	Oct.	18	9.14	0.30	3.3	0	1.94	30.0	2.49	1.5	3.99	0.27	5.0	0.44	122	27	125
58	Nov.	28	8.75	0.57	6.5	0.04	1.95	15.9	2.45	1.8	4.25	0.28	3.2	0.49	118	37	365
59	Dec.	31	7.36	0.51	6.8	0.01	2.33	18.1	2.23	2.0	4.23	0.30	4.0	0.57	153	35	455
60	Jan., 1931	31	6.82	0.76	11.1	0.06	2.40	12.1	2.40	2.0	4.40	0.35	2.6	0.65	160	33	515
61	Feb.	28	7.38	0.75	10.2	0.09	2.23	12.1	3.47	1.0	4.47	0.47	1.3	0.61	180	42	410
62	Mar.	31	9.02	0.72	8.0	0.08	1.86	12.6	2.52	1.5	4.02	0.28	2.1	0.45	145	34	518
Average		**24**	**9.95**	**0.81**	**8.1**	**0.035**	**1.75**	**16.6**	**2.83**	**1.3**	**4.13**	**0.29**	**2.77**	**0.44**	**142**	**30**	**310**

NO SLUDGE RETURN TO AERATION

40	Sept., 1929	25	9.35	0	0	0.51	2.78	0	3.88	0	3.88	0.41	0	0.41	180	30	69
42	Nov.	36	9.16	0.04	0	0.44	2.86	0	4.36	0	4.36	0.47	0	0.47	154	31	105
45	Jan., 1930	15	11.65	0	0	0.60	2.24	0	5.05	0	5.05	0.43	0	0.43	119	24	120
47	Mar.	10	12.55	0	0	0.14	2.17	0	4.89	0	4.89	0.39	0	0.39	102	29	116
54	Aug.	8	9.15	0	0	0.54	1.89	0	2.85	0	2.85	0.31	0	0.31	115	42	85
							(4 tanks)										
55	Aug.	14	10.03	0	0	0.56	2.60	0	3.99	0	3.99	0.40	0	0.40	103	40	95
63	Apr., 1931	25	9.50	0	0	0.23	2.83	0	4.15	0	4.15	0.44	0	0.44	112	35	148
Average		**19**	**10.20**	**0**	**0**	**0.43**	**2.48**	**0**	**4.17**	**0**	**4.17**	**0.41**	**0**	**0.41**	**126**	**33**	**105**

age of 385 p. p. m. These first eleven periods and also Period 15 do not represent operation under the conditions for which the plant was designed. However, they are of considerable experimental significance, showing the effect of longer aeration periods on this sewage-starch waste mixture. Likewise Periods 35, 36 and 37 represent experimental results which show the effect of longer aeration periods, with sludge re-aeration. These two sets of experimental data are plotted with the other data in Figure 1 and will be discussed more fully later in the paper.

The dilution water for the biochemical oxygen demand test during Periods 27 to 31, inclusive,[7] was faulty and although methods of correction were applied the results were not consistent with the general appearances of the effluents and with other data so they have been eliminated from Table II. Therefore Table II contains only data when all the sewage flow (from 8 to 14 m. g. d.) was passed through the aeration plant and does not include five periods when the B. O. D. results are questionable. The purpose of this table is to compare the three methods of operation.

Excess Sludge.—No excess sludge was returned to the Imhoff tanks for digestion during the first 16 months because the sludge did not build up to a sufficient concentration to warrant any return for digestion. Instead of building up, the sludge remained thin because it was so light and fluffy that it almost continuously bulked over the clarifier weirs and passed to the sprinkling filters. There was from 10 to 20 p. p. m. more suspended matter in the settled effluent than in the influent to the aeration tanks. These solids did not clog the filters, however, nor show any tendency to cause ponding.

Since July, 1929, the secondary tank humus has been pumped back into the aeration-tank sludge line every four hours and sludge accumulation has been much greater, particularly with the "re-aeration" method of operation. It has been found impractical to keep much more than 500 p. p. m. of sludge in the aeration tanks because of the limited aeration period. As will be shown more clearly later in this paper, the plant evidently has a definite capacity for satisfying the oxygen demand of the sewage and sludge and when the sludge in the system becomes too concentrated this capacity is overtaxed, with the following results: (1) the sludge becomes septic and the aeration tanks as well as the sprays on the filters emit hydrogen sulphide odors and (2) *Sphaerotilus*-like organisms develop and the sludge bulks heavily over the clarifier weirs onto the sprinkling filters. A very black septic sludge settles quite satisfactorily without bulking but produces very strong odors.

Morgan and Beck[8] have reported on the growth of *Sphaerotilus* in activated sludge due to sugar from illegal mash operations. Although fairly well controlled, the Decatur sewage is subject to occasional sugar losses from the starch works, which cause growths of *Sphaerotilus*-like

organisms in the sludge, even when the sludge is apparently not in a septic condition. These growths of *Sphaerotilus* are always accompanied by a rather characteristic odor that is not a typical septic sewage odor.

Normal Aeration.—Table II contains records of 345 days of operation which have been divided into 18 "normal aeration" periods. These periods cover a few winter months and more in warm weather, and numerous variations in volume of sludge returned and air applied. The return of large volumes of sludge is not significant from a sludge quantity point of view because the density of the sludge is inversely proportional to the volume of sludge liquor pumped. A large sludge return does not increase the amount of suspended solids in the aeration tanks but does decrease the aeration period and in that way has a tendency to decrease the efficiency of the treatment. There is an indication that with larger volumes of air applied greater reductions in B. O. D. removal are accomplished. This was not true in Periods 22 and 23 but in these the sewage B. O. D. increased considerably and caused a deterioration in the process.

The averages for the "normal aeration" periods are: sewage flow 9.83 m. g. d., sewage aeration period 2.54 hours, air applied 0.48 cu. ft. per gal. of sewage, influent B. O. D. 163 p. p. m. and B. O. D. removal 32 per cent. The suspended matter both in volume and weight was consistently greater in the settled effluent than in the influent.

Re-Aeration.—Table II contains records of 437 days of operation which have been divided into 18 "sludge re-aeration" periods. These periods included mostly winter and spring months but also a few summer and fall months. With re-aeration a better sludge was maintained, with a good brownish color and microörganisms present. This sludge was denser and settled better most of the time than the sludge produced without re-aeration. It had to be watched quite carefully and excess sludge had to be returned to digestion regularly or it would bulk, get out of control and spoil the monthly or period averages. In every way the process with re-aeration appeared to work better than the other two methods of operation discussed in this paper.

The surprising fact is that the laboratory data did not show any improvement in B. O. D. removal. The average removal of B. O. D. for these 18 periods was 30 per cent, which is 2 and 3 per cent less than was obtained with the other two methods of operation. It is believed that this difference is not significant but it does indicate that better efficiencies or removals were not obtained with sludge re-aeration. The averages for the "re-aeration" periods were: sewage flow 9.95 m. g. d., sewage aeration period 1.75 hours, sludge re-aeration period 16.6 hours, air applied 0.29 cu. ft. per gal. sewage and 2.77 cu. ft. per gal. sludge or an over-all total application of 0.44 cu. ft. per gal. of sewage treated, influent B. O. D. 142 p. p. m. and B. O. D. removal 30 per cent.

Because of the greater quantity of organic matter in the sludge and the higher oxygen demand, it seemed logical to introduce more air or agitation in the sludge re-aeration tanks than in the sewage aeration tanks. This was done in December, 1930, January and March, 1931 (Periods 59, 60 and 62), with resulting B. O. D. removals of 35, 33 and 34 per cent. During February, 1931 (Period 61), the air distribution was changed so that only moderate agitation was obtained in the sludge re-aeration tanks, and rather vigorous agitation in the sewage aeration tanks. The B. O. D. removal for this period was 42 per cent. This one period would not be convincing but a study of all the periods indicates that the maximum per cent removals of B. O. D. have usually occurred when plenty of air was used with "re-aeration," "normal aeration" and "no sludge return."

No Sludge Return.—There are 7 periods in Table II totaling 133 days, which include all four seasons of the year, in which no sludge was returned to the aeration tanks. These data indicate clearly that the average results were equally as good if not better than those obtained by "normal" or "re-aeration" methods, both of which contained returned sludge. The average results of the operation of these 7 periods were: Sewage flow 10.2 m. g. d., sewage aeration period 2.48 hours, air applied 0.41 cu. ft. per gal. of sewage, influent B. O. D. 126 p. p. m. and B. O. D. removal 33 per cent.

The suspended matter results show that there is a slight production of sludge in the aeration tanks with this method of operation. Under the microscope this sludge seems to be made up of zoögloeal sludge masses but does not contain as many *Z. ramingera* or *Z. compacta* as do the other sludges, nor does it contain the protozoa reported in the other sludges. There is, however, a very fine mosaic of filamentous organisms which cover the slide but which grow differently than the *Sphaerotilus* found in the other sludges.

In order to get further data on the effect of different amounts of air, Period 64 was started in May, 1931. There is always the question in comparing two different periods, whether some change in the sewage did not cause the particular results obtained, instead of the change of operation. With "normal aeration" and "re-aeration" it is difficult to study the effects of differing volumes of air in each pair of tanks at the same time, because the sludge returned is a mixture from all three pairs of aeration tanks and thus may discredit the results from any one tank. However, with "no sludge return" it is possible to study the effect of three different rates of aeration simultaneously on the same sewage. The distribution of air to the three pairs of tanks and the B. O. D. removals are presented in Table III. In brief, the results for applications of air at rates of 0.172, 0.288 and 0.417 cu. ft. per gal. of sewage were 17.5, 28.8 and 37.2 per cent removals of B. O. D., respectively. With different sewage strengths and

compositions, as well as seasons of the year, these per cent removals will not be reproducible, but the relative removals are definitely shown to be proportional to the amount of air introduced when such other factors as sewage, aeration period, design of tanks, temperatures, rain, etc., are identical for each tank. This same relation may hold true for "normal aeration" and "re-aeration."

TABLE III

THE EFFECT OF VOLUME OF AIR ON B. O. D. REMOVAL

Tank Pair	Sewage Flow, M. g. d.	Hours Aeration	Air Distribution: Mil. Cu. Ft. per 24 Hrs.	Air Distribution: Cu. Ft. per Gal. Sewage	Air Distribution: Cu. Ft. per Min. per Plate	Velocity of Sewage: 6 In. below Surface, Ft./Sec.	Velocity of Sewage: 3 Ft. below Surface, Ft./Sec.	B. O. D. Influent to Tanks, P. p. m.	Per Cent Removal
1	3.48	2.64	0.6	0.172	8.47	2.65	0.88	101	17.5
2	3.48	2.64	1.0	0.288	14.1	3.38	1.17	101	28.8
3	3.48	2.64	1.45	0.417	20.5	3.67	1.20	101	37.2

Biological Examinations.—Almost continuously since the plant was started in 1928, microscopic analyses of the sludge have been made. The plant has operated at various times with little or no motile life visible in the sludge under the low-power microscope; with numerous flagellates; with holotricha; with very active hypotricha; with numerous peritricha, suctoria and rotifera; and with combinations of the above groups. The presence of peritricha, suctoria and a few rotifera usually indicate that the Decatur sludge is in a good activated condition. However, a careful analysis of the records since January, 1928, does not show a correlation between protozoa present and percentage removal of B. O. D. except that equally good results were secured in their absence.

By far the largest amount of the sludge material is what Buswell has called "zoögloeal sludge masses."[2] These sludge masses with filamentous organisms are all that are visible when the operation is with "no sludge return." With "normal aeration" the zoögloeal sludge masses are augmented with a rather extensive growth of *Zoögloea ramingera* and *compacta*, occasional *Sphaerotilus*, and usually some hypotircha, and occasionally peritricha. With "re-aeration" the sludge is still made up chiefly of zoögloeal masses and *Z. ramingera* and *compacta*, but is further characterized by the number of peritricha present.

The two constant factors are the removal of B. O. D. and the presence of zoögloeal sludge masses. The bacterial count is also higher in the aeration liquor than in the influent sewage. It would seem that these two factors, bacteria and zoögloeal sludge, together or individually are the biological factors in pre-aeration sludge.

Discussion.—The data indicate clearly that the pre-aeration plant as it exists and as it is operated under the three methods of operation reduces the influent B. O. D. between 30 to 40 per cent. This reduction takes place

either in the presence or absence of returned sludge. This reduction must be the easily oxidizable matter that is removed by chemical oxidation, mechanical sweeping out of solution of volatile matter or biological decomposition that takes place very rapidly. If the purification is biological, sufficient inoculation must exist on the walls of the aeration tanks or be introduced from the return sludge which is mixed with the raw sewage before settling in the Imhoff tanks.

These reductions are of the same order of magnitude as those shown by Theriault[9] for one-day oxygen depletions at 20° C. in incubation bottles. Further, it seems probable that the pre-aeration plant is oxidizing the immediate demand, the velocity constant of which Theriault[9] has shown to be from 16 to 20 times as great as the normal rate of de-oxygenation.

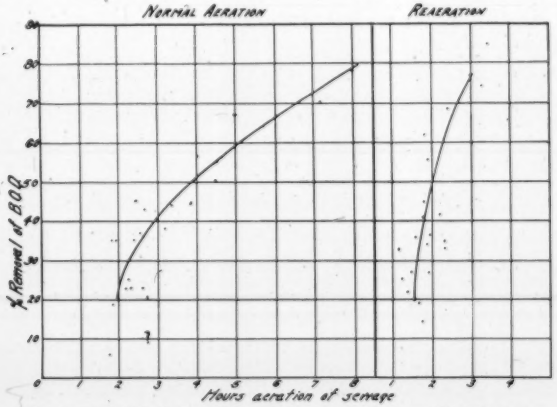

FIG. 3.—Relation of Time of Aeration to Per Cent Removal of B. O. D.

These results may be of value in the development of the theory of the mechanism of activated-sludge treatment, since the pre-aeration results may be the first and rapid step in the process. Undoubtedly this part of the process is not dependent on protozoa since their absence has no effect on the efficiency.

Ardern's observation is confirmed, that the presence of considerable numbers of the larger ciliated protozoa are coincident with very complete removal of turbidity in the effluent. These protozoa may contribute to the final step in the activated-sludge process, *i. e.*, clarification, and also may aid the oxidation processes by maintaining an active bacterial population as shown by Butterfield, *et al.*[3]

The relation between B. O. D. removal and hours of sewage aeration is shown in Figure 3. With the displacement periods of the Decatur plant of 2.5 hours for "normal" aeration and 1.75 hours for "re-aeration" the same percentage of B. O. D. removal is shown. However, somewhat better results are indicated if longer aeration is allowed with 16 hours of sludge re-aeration. For example, if 3 hours of sewage aeration with "re-aeration" is allowed, the removal of B. O. D. is 75 per cent; this is comparable with 4.5 hours of "normal" aeration (in the same sized plant), which should give 55 per cent removal of B. O. D.

Odor is another factor which should be considered in comparing the three methods of operation. Odor is an elusive element and cannot be recorded in numerical averages. Usually there is little or no offensive odor from the aeration tanks and sprinkling filters, but about twice a month a strong sewage (probably industrial wastes) that causes odors is received. The odor hazard from the aeration tanks and filters is apparently greatest with "no sludge return," less with "normal aeration" and least with "re-aeration." The larger amount of relatively good activated sludge in the system during "re-aeration" absorbs or oxidizes the odors and reduces the odor hazard, provided the sludge is carefully watched and not allowed to overload the oxygen-satisfying capacity of the plant. In the latter case the sludge odors are as bad as the other odors. With proper attention less odors are noticeable during periods of "re-aeration."

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Starting and Operation of the Collingswood, New Jersey, Activated-Sludge Plant*

BY I. O. LACY**

The sewage disposal plant at Collingswood, N. J., has been described by the designing engineer.[1] Some few features have been added to make the entire operation more mobile.

The plant was designed to treat 1.33 million gallons per 24 hours of domestic sewage. The sewage is aerated with Link-Belt mechanical aerators, which receive the sewage after it has been chlorinated and settled for one and one-half hours in a mechanically cleaned preliminary settling tank of the Link-Belt type. The final settling tanks are followed by chlorination. Separate-sludge digestion is practiced; the supernatant liquid is drawn on to one of the glass-covered sludge beds and the effluent returned to the influent channel. Arrangements have been made to return volumes of activated sludge to the preliminary settling tanks.

The plant was not fully completed, although partial operation was under way, on July 8, 1930. The first aeration tank was full of aerated sewage, and sludge that had acquired a fine brown color by its constant agitation and subsequent aeration during a three-month period. The method used was to allow some fresh sewage to enter the tank for a period of one to two hours each day, returning the sludge collected in the final settling tank to this same aeration tank. An analysis of the contents of this tank showed it to contain 8.22 p. p. m. of suspended solids with 30 per cent ash, while the liquid from the settled aeration-tank mixture contained 4 p. p. m. dissolved oxygen. The entire flow of sewage was being aerated in Tanks 2 and 3 during this period. The sludge accumulating in the final settling tanks was returned to an old digestion tank.

After one week of aeration the first tank did not accumulate more suspended solids, consequently it was deemed advisable gradually to put a second tank into operation and thereby build up a better floc. The entire flow was divided equally between the first two tanks, the sludge accumulating in Tank 1 was returned to the second tank for a period of two hours, then the entire flow was diverted to the third tank. The contents of the first two tanks were allowed to be agitated in this manner for 16.5 hours. The two tanks appeared to contain the same quality of sludge, therefore some sewage was allowed to flow into each of the first two tanks, with 75 per cent of the sludge going to the second tank and 25 per cent to the first tank. The third tank was used to aerate the sewage. For a few hours (3) this operation continued, then the return sludge was cut off. Although

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the sludge formed in the raw sewage after aeration was removed twice a day, it was found to be quite necessary to clean the final settling tanks thoroughly before returning any of the sludge to the aeration tanks.

B. O. D. Reduction of Aerated Sewage

The fourth aeration tank contained only aerated sewage. The question arose whether or not there would be an appreciable reduction in the B. O. D. value without returning any sludge to the tank. If a reduction of any appreciable amount could be gained in a short time (30 minutes) such type of aeration might be used as an adjunct to overloaded plants. To test this possibility the inlet to the tank was closed, and a sample taken just prior to the closing. Samples were then taken below the surface from the middle section of the tank at fifteen-minute intervals, the dilutions being made immediately and placed in a 20° C. incubator to remain for five days. The following B. O. D. values were recorded:

Influent	380 p. p. m.
After 15 min.	340 p. p. m. reduction 10.5%
After 30 min.	360 p. p. m. reduction 5.3%
After 45 min.	250 p. p. m. reduction 34%

Loss of Floc

Some difficulty was encountered in maintaining the floc in the first three aeration tanks. To increase the volume and concentration of the floc Tank 2 was bypassed, only aerating the sewage, and putting in operation Tank 4, which contained only raw aerated sewage. Forty-eight hours after starting this tank, Tanks 1, 3 and 4 contained, respectively, 660, 588 and 622 p. p. m. of suspended solids. These solids settled out fairly well in one hour, with a clear supernatant liquid, the settlement in a liter graduate showing 30, 32 and 30 per cent floc. It should be kept in mind that no sludge was being returned to these tanks, and very little sewage was allowed to enter. Some sludge was returned to Tanks 1, 3 and 4 the next day, but it was quite thin, since the hydrostatic head on the sludge lift was not sufficient to overcome the settling characteristics of the sludge when the valves were opened only wide enough to allow the return of the heavy sludge. More sewage was then allowed to enter to raise the level in the final settling tanks so that a denser returned sludge was available. Whereas the returned sludge had settled to 40 per cent it now settled to only 80 per cent in one hour.

The fourth aeration tank is somewhat larger than the first and second and it was found necessary to manipulate the returned sludge valve to allow more sludge to enter because the suspended solids content was gradually decreasing. The solids content, however, did not increase, therefore Tank 2 was cut in. The flow was now quartered, all the returned sludge was

added to Tank 2 for two and one-half hours, then the other return valves were opened and some sludge returned to them as well. Unfortunately, it was impossible to measure the amount of returned sludge owing to lack of facilities The volume of returned activated sludge could be estimated only by opening valves to a greater or less extent. Tank 2 contained only 103 p. p. m. of suspended solids after this period, the other three tanks remaining nearly constant in their solid content, namely, 700 p. p. m.

It appeared that when returning 20 per cent or more activated sludge it was difficult to maintain a good floc and poorer results were produced than with an estimated return of 10 per cent by volume The amount of sludge returned was therefore maintained at about 10 per cent of the sewage flow. Since no measuring device was available these volumes were estimated from the flow through the return inlet pipes.

Sludge in the final settling tank of Tank 2 was unsatisfactory, the returned material maintaining a black color, consequently the tank was pumped clean and scrubbed down. There was very little sludge on the bottom of the tank, but the liquid was very dark in appearance. Under the valve boxes a layer of black septic solids was found which was about 1 inch thick. During this period all the sewage was treated in three tanks. The next morning the final settling tanks seemed to have a fine floc scattered throughout the entire volume, giving the appearance of gravel wash water. This became black and septic, although no odor was noticed. The other three tanks were then similarly cleaned. No sewage was added to the first three aeration tanks during this period of cleaning. Operation was then resumed.

Gradually the suspended solids content, as shown by settling tests, became greater in the first three tanks. No sludge was returned to the fourth tank. The final settling tanks were clearing up slowly. It seemed that a large floc could be built up quite rapidly in the aeration tanks, but it would not settle even though only 663, 622, 584 and 538 p. p. m. suspended solids were present in the four tanks, respectively. During this period the chains on the agitators broke several times; finally heavier chains and sprockets were introduced, which remedied the trouble.

Operation Resumed

The floc was not building up although sludge was returned to the aeration tanks. After several days the condition of the tanks became no better so it was decided to clean the tanks and to start again. The suspended solids concentration was built up slowly by manipulating the influent and the returned sludge. In a few days the final settling tanks were very clear and the bottom could be seen, although the floc settled rather slowly. After a few more days the floc settled rather rapidly in the three tanks that were operating but it seemed impossible to retain more than 700 p. p. m.

suspended solids. Chemical analyses made at this time on samples showed the following:

	Ammonia, P. p. m.	Nitrite, P. p. m.	Nitrate, P. p. m.
Influent	60	0	0
Eff. Aeration Tank 1	40	0.5	0.96
Eff. Aeration Tank 2	50	1.00	3.2
Eff. Aeration Tank 3	50	1.50	3.2
Eff. Aeration Tank 4	50	1.50	3.2

Tank 1 had no activated sludge in it at this time.

Once again all four tanks were operated. More sewage was allowed to flow into Tanks 3 and 4 than into 1 and 2. Tank 1 accumulated solids quickly and in four days it contained 709 p. p. m. suspended solids while the others contained 608, 567 and 540 p. p. m., respectively. However, the sludge again became very coarse, the floc being quite large. By cutting down the amount of returned sludge to the aeration tanks this condition soon rectified itself, and the effluent cleared up.

Digestion

The sludge-digestion tanks are of a design similar to those at Merchantville-Pensuaken, consisting of long channels, with flat slab roofs. The digestion capacity is 3.3 cubic feet per capita. The tanks were seeded with sludge from the old treatment plant. During the first six months the tank filled with sludge rapidly and by the middle of January, 1931, when the heating system was started, it was full of sludge without any liquid layer. Daily additions of fresh solids amounted to never less than 570 and often to 1400 cubic feet. The first withdrawal was about 1900 cubic feet of sludge with a concentration of 5.0 per cent solids.

However, even after the temperature of the digestion tank had been raised to 72° F. for a period of two weeks there was no liquid level in the tank, and the solids content at the outlet end of the tank was constant throughout the entire depth.

The withdrawal of sludge proved to be of no value because the night operators, after drawing the sludge from the primary settling tank, neglected to close the valves. The digestion tanks filled to overflowing, the overflow passing through a valve outside the digesters, through the clarification tanks and into the aeration tanks. For a period of about two weeks after the digestion tanks were re-seeded it was possible to draw some supernatant liquid. This liquid, with a B. O. D. of 250 p. p. m., was run on a sand bed and after filtration returned to the influent. This material, although very hard to treat, had to be returned because it is impossible to bypass any stage of the treatment process.

Hydrogen Sulphide

The plant is built at the site of the old sewage disposal plant and a number of houses have been built during recent years in front of and alongside the plant. The nearest houses are about 100 feet distant. The raw sewage contained about 4 p. p. m. hydrogen sulphide, which caused a nuisance in the surrounding homes. A chlorinator was installed, which was regulated to add sufficient chlorine to reduce about 60 per cent of the H_2S, as shown by tests.

Short Circuiting

To test the possibility of short circuiting, ammonia tests were made at different levels and at different points of an aeration tank, using various flows. At each point the surface sample was similar to the sample taken at varying depths from the same sampling position. There was apparently no short circuiting which could be detected by this test.

Increasing Speed of Aerators

The aerators revolved at 44 r. p. m. until the first week in December, 1930. With the installation of a new sprocket on one drive shaft the aerators were made to revolve 54 r. p. m. The tank showed improvement in less than 24 hours. The final settling tank, which did not have a good color, cleared up immediately and the sludge settled more rapidly. The aerators on the other tanks were accordingly speeded up. The improvement was noticed in all tanks. The velocity at the bottom of the tanks was slightly more than 1.5 feet per second.

Effect of Addition of Air

Before the sprockets were changed on all the drive shafts, the question was raised as to what effect air would have as an adjunct to the mechanical aeration. A 30-foot section of 1-inch galvanized iron pipe was perforated with $^1/_{16}$-inch holes at frequent intervals. This pipe was laid on the bottom of the tank and connected with an air line from the compressor. The air did not increase the velocity of the liquid and did not affect the reduction

TABLE I

AMMONIA DETERMINATIONS IN TANKS WITH AND WITHOUT COMPRESSED AIR*

Sampling Place, Feet from Inlet	Tank 2			Tank 1		Tank 3
	Run A, P. p. m.	Run B, P. p. m.	Run C, P. p. m.	Run A, P. p. m.	Run B, P. p. m.	Run C, P. p. m.
0	45	40	40	45	40	40
45	50	35	35	40	30	35
60	45	40	40	40	30	30
90	45	35	40	40	30	30
120	45	35	35	30	30	30

* Auxiliary air supplied in Tank 2, 0–45 ft. from inlet.

in ammonia nor increase the nitrites as measured against the other tanks that were in operation. The results for ammonia nitrogen are given in Table I; the nitrates were constant in all cases.

Clarifier Efficiency

In order to determine the efficiency of the primary clarifier during a 24-hour period, samples were taken every fifteen minutes and composited. At intervals suspended solids and total solids were determined. The results are graphically shown in Figure 1. Over this period, with a flow approxi-

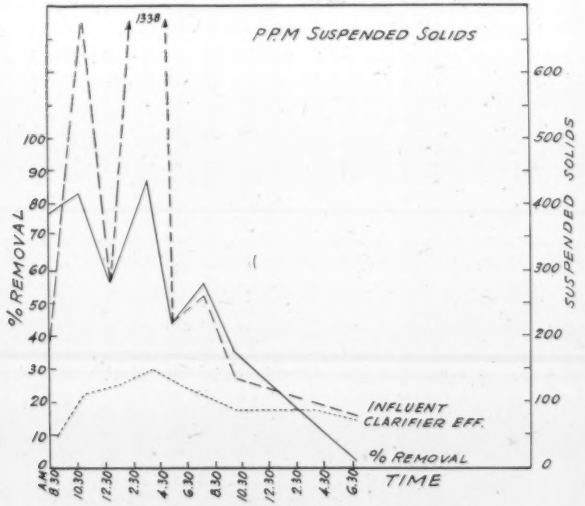

FIG. 1.—Suspended Solids Reduction of Raw Sewage.

mating 1 m. g. d., the average p. p. m. suspended solids entering the tank was 370 and the effluent contained on an average 103 p. p. m. These figures alone would tend to show a removal of 72 per cent. Several samples contained a very large content of suspended solids, thus tending to raise the average. At 3:15 P.M. when the influent contained 1338 p. p. m. (Figure 1) suspended solids the effluent contained 150 p. p. m., thus indicating 89 per cent removal. On the other hand, when the sewage contained from 175 to 250 p. p. m. suspended solids, the effluent contained from 90 to 110 p. p. m., thus giving a percentage reduction varying from 27 to 52 per cent.

The average monthly removal of suspended solids for the period August to December, 1930, were as follows:

Month, 1930	Average Inf. Susp. Solids, P. p. m.	Average Clar. Eff. Susp. Solids, P. p. m.	Weighted Aver. Per Cent Red., P. p. m.
August	245	76	67
Sept.	198	68	63
Oct.	275	95	59
Nov.	339	200	41
Dec.	255	234	8.5
Average	262	134	49

During the month of December several rather irritating occurrences during the night affected the operation considerably, such as allowing the scrapers to run all through the night, leaving valves open, etc.

During November and December activated sludge was constantly returned to the influent end of the preliminary clarifier, the amount not being known. The pH of the influent during this same period averaged 6.8 and of the clarifier effluent 6.9.

B. O. D. Reduction by Chlorination

As has been often stated with data from other sources, chlorine will reduce the B. O. D. of the sewage. Much depends upon the amount of chlorine used and the character of the sewage. At Collingswood, owing to the closeness of occupied homes to the plant, the authorities deemed it wise to introduce chlorine in the influent. The chlorine was introduced in the influent channel at a point about 4 feet before the entrance to the primary settling tanks. Almost immediately after the chlorine is introduced the sewage enters the preliminary clarification tanks over two 90° weirs. Samples were taken at this point of fall and also at the same time as the sew-

TABLE II

B. O. D. OF RAW AND CHLORINATED SEWAGE

Inf., P. p. m.	Cl_2 Inf., P. p. m.	Per Cent Red.	Clar. Eff., P. p. m.	Per Cent Total Red.
435	320	26.5	255	41.4
525	495	5.5	360	46.0
620	545	12.0	345	44.4
410	445	+8.5	235	42.5
430	420	2.3	180	58.0
380	370	2.6	430	+13.0
410	370	10.0	275	33.0
920	740	19.3	560	38.0
630	535	15.0	500	21.0
860	720	16.1	800	7.0
500	440	1.2	300	40.0
Aver. 550	490	9.3	385	32.6

+ = increase.

age left the influent pipe lines. Samples were also taken as the clarified sewage was being distributed into the various aeration tanks. From samples taken at the above mentioned points, five day B. O. D. determinations were made over a period of one month. Some of these results are presented in Table II and plotted in Figure 2.

During this period the average flow, as taken from the operator's report, was 469,026 gallons per 24 hours. Chlorine was added at a rate of 23 lb.

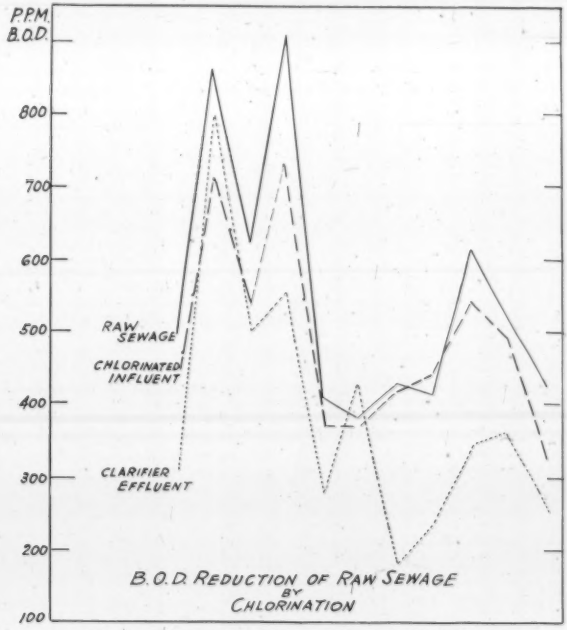

FIG. 2.—Effect of Chlorination on B. O. D. Reduction.

per million gallons, or approximately 5.5 p. p. m. This quantity of chlorine did not give a residual chlorine test in the primary clarification tanks. Experiments showed that residual chlorine would break up the tendency to floc. The real purpose of the work was to control the odor, and this was accomplished. In fact, half this amount of chlorine controlled the odors to a satisfactory extent.

Ammonia Reduction

During the entire period numerous analyses were made for ammonia, nitrite and nitrate nitrogen. These tests showed that there was a slight over-all reduction in ammonia, usually from 45 p. p. m. N as NH_3 in the influent to 40 p. p. m. in the final effluent. The reduction took place entirely in the clarifier. It is possible that a part of the NH_3 reduction was due to the addition of chlorine. Samples taken at different points in the aeration tanks did not show a reduction in ammonia but quite often a rise and fall. No nitrites appeared until after the aeration tanks; simultaneously with the appearance of nitrites, nitrates were found in the aeration tank effluent to the extent of 1.92 p. p. m.

The methylene blue color remained in the final effluent for at least five days, except during the first month of operation.

Flow

The plant was designed to treat 1,300,000 gallons per 24 hours. The average, minimum and maximum daily sewage flows received at the plant for the period October, 1930, to January, 1931, inclusive, are given in Table III.

TABLE III

DAILY AVERAGE, MINIMUM AND MAXIMUM FLOW

Month	Gallons per 24 Hours Average	Minimum	Maximum
Oct., 1930	688,280	616,810	762,200
Nov., 1930	610,430	443,400	801,830
Dec., 1930	469,026	339,680	945,600
Jan., 1931*	530,700	370,000	718,130
Feb., 1931	932,900	523,800	1,180,800

* Part of record inaccurate.

General Results

Additional operating results are presented in Table IV. B. O. D. results for the first four months were not accurate, due to lack of a satisfactory

TABLE IV

AVERAGE MONTHLY RESULTS—COLLINGSWOOD PLANT

Date	Suspended Solids Inf.	Clar.	Final Eff.	Ash Inf.	Clar.	Final Eff.	Turbidity Inf.	Final Eff.	Meth. Blue Eff., Days	pH Inf.	Clar.	Final Eff.
Aug.	244	76	99	26.4	23.3	26.0	189	185	3.5	6.9	6.7	7.0
Sept.	198	73	82	25.2	36.0	26.4	204	158	5.2	6.8	6.6	7.1
Oct.	276	95	45	23.5	17.7	25.3	512	111	9.5	6.9	7.0	7.2
Nov.	340	200	54	21.4	19.0	15.0	538	90	7.1	6.9	7.0	7.3
Dec.	256	235	51	14.3	13.7	16.2	380	99	7.1	6.8	7.0	7.3
Aver.	264	140	64	21.0	22.0	23.0	368	140	6.5			
Aver. % Red.		47	76					62				

incubator. The average 5-day B. O. D. results for the month of December, 1930, were—influent, 550 p. p. m., and effluent, 25 p. p. m., or an over-all reduction of 95 per cent.

The stream (Newton Creek) into which the effluent is discharged, is affected very slightly by the tide, and during the warm months is quite full of algae. The oxygen saturation of this stream has always been above 75 per cent.

During the months of November and December, 1930, all of the activated sludge was returned to the primary settling tanks. The amount of this sludge not settling was used as the seed for the aeration tanks.

Cost of Operation

Data for calculating the cost of operation of the plant and its different units were kindly supplied by Mr. W. Dare, City Engineer of Collingswood. The total cost of electricity for the months of October, November, December, 1930, and January, 1931, was $2960, which included connecting charges and pumping cost (one pumping station) amounting to $420, and the lifting charges at the plant amounting to $424, or a total cost for electricity for the operation of the aerators, compressor and settling tanks unit of $2116. (This includes cost of electricity for lights, incubator, etc.)

The power consumption, calibrated during this period by the Link-Belt Company, was as follows:

40 Hp. motors	(4–10 hp. motors for aerators) used daily	31 hp.
3 Hp. "	(final settling) used daily	2.25 hp.
2 Hp. "	(preliminary settling) used daily	0.13 hp.
20 Hp. "	(compressor) used daily	17.5 hp.
		50.88 hp.

The total power consumption for 4 months was 135,712 k. w. h. and the total flow 61.4 million gallons of sewage.

The actual cost of power for the different months, including lights around the plant, was as follows:

Oct. 16–Nov. 16	$538.15
Nov. 16–Dec. 16	549.11
Dec. 16–Jan. 16	658.47
Jan. 16–Feb. 16	689.60

During the first two months the aerators revolved at a rate of 44 r. p. m. and during the second two months at a rate of 54 r. p. m. The increase in the rate of revolutions of the aerators cost, therefore, about $135 per month. Charges for power at Collingswood are 3¢ for the first 400 k. w. h., 2¢ for the next 600 k. w. h. and 1¢ for the remaining k. w. h. The power cost for

operation (exclusive of lights, etc.) of the plant, expressed per million gallons sewage treated, was on the basis of rate consumption $29.02 and on the basis of the calibrated consumption, $23.42.

Acknowledgment

The writer wishes to acknowledge the coöperation of Mr. Tark of the Link-Belt Company, which furnished part of the equipment; the staff of Remington, Vosbury and Goff, the designers; and the work of the superintendent, Mr. Dare, and operating staff of the Borough of Collingswood. Dr. Rudolfs generously gave of his time and experience on the tests and writing of the report.

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[1] D. W. Vosbury and P. B. Streander. "Activated-Sludge Plant Using Mechanical Aeration at Collingswood, N. J." *Public Works.*, **62,** 26 (Jan., 1931).

Allentown Sewage Treatment Works*

BY HARRY KRUM**

Sewage disposal has been a matter of public concern and discussion in Allentown for many years. The city is located in a limestone area and is built on a plateau at the base of which is located Crystal Spring, the original source of the city's water supply. The part of the city above the spring has developed into a residential section, and for each house erected a cesspool was dug. The condition resulted in the condemnation of this spring.

In the years 1897, 1903 and 1908 the citizens were not yet educated to the advantages of a sewerage system and defeated proposed bond loans for that purpose. It was not until the year 1920 that the city commissioners were able to borrow sufficient money to build the first section of a sewerage system and disposal plant. The section of the city selected to be connected with the sanitary sewers was that nearest the Crystal Spring. In August, 1921, the first sewage treatment plant was put in service. This plant employed the Landreth Direct Oxidation electrolytic method. The plant was in operation for eight years and was abandoned when the new plant was ready to receive sewage. The old plant cost approximately $200,000 and the average amount of sewage treated was 1.5 million gallons per day.

After the construction of the new treatment plant a trunk sewer was connected with the sewer entering the old plant and the sewage now flows from this point to the new plant by gravity. The settling basins of the old plant, which is located in Fountain Park, are now used as public bathing pools.

The important function that the old plant performed was to make the citizens of Allentown sewage-minded. When the last bond issue was submitted to the citizens it was approved, with the result that we now have a new sewage treatment plant and eighty miles of sanitary sewers to which additions are constantly being made.

Description of Plant

The City of Allentown has a population of 97,000 which is served by a separate sewerage system. The treated sewage flows into the Lehigh River which flows through the city. Five miles downstream is located the City of Bethlehem—whose water supply is taken from the river. Eighteen miles east of Allentown, the river joins the Delaware River.

The sewage disposal plant is built on Kline's Island, located in the Lehigh

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** *City Chemist, Allentown, Pa.*

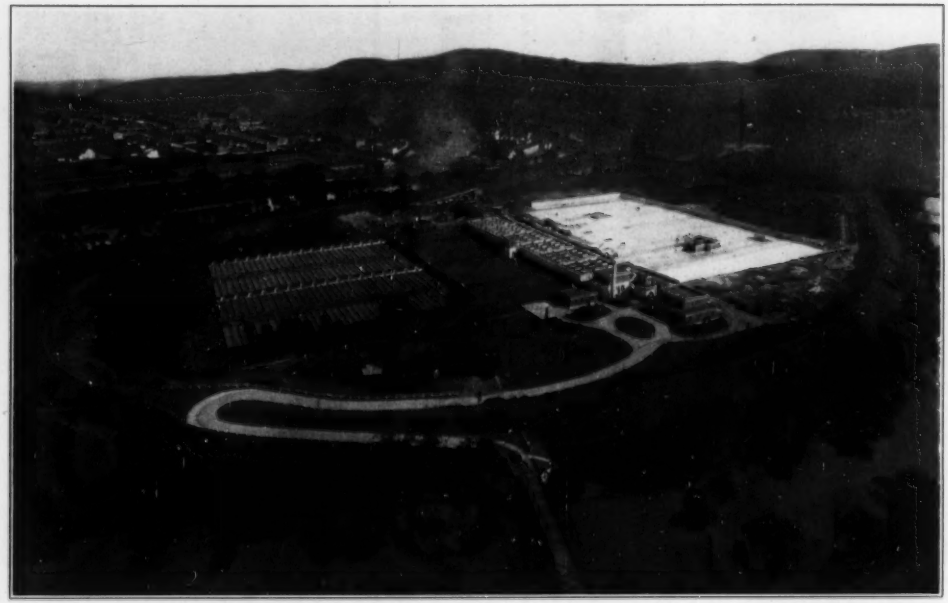

FIG. 1.—Allentown Sewage Treatment Works. Center, Pumping Station, Screen Chamber and Imhoff Tank. Right, Trickling Filters. Left, Sludge Beds. Center Distance, Excavation for Humus Tanks.

River. The island is within the city limits but is more or less isolated because the railroads occupy both banks of the river opposite the plant, making the area industrial rather than residential. The entire island is surrounded by a dike to elevation 32, six feet higher than the maximum recorded flood level.

The new disposal plant was designed by City Engineer Earl Meckley and Consulting Engineers Metcalf & Eddy, of Boston.

The plant consists of a rack chamber, pumping station and laboratory, two detritus tanks, screen and incinerator house, six Imhoff tanks, ejector house, chlorinating house, sludge beds and garage. It was designed for an estimated population of 128,000 in 1935 with an average daily flow, at that time, of 17.3 m. g. and a maximum of 34.6 m. g. The capacity of the main sewer entering the plant is 59 m. g. d. The plant is so arranged that similar duplicate units may be added to double the present capacity.

The incoming sewer is provided with an overflow for emergency use only, such as might result from interruptions of power.

Rack Chamber.—A rack chamber is provided to prevent large objects from entering the pumps. The racks are made of parallel steel bars in three sections, each $9\frac{1}{2}$ ft. long by 1 ft., 10 in. wide, having a clear spacing of 3 inches.

Pumps.—The main pumping equipment consists of three motor-driven centrifugal pumps. These pumps comprise a 4000 g. p. m. (5.76 m. g. d.) pump direct connected to a 60 hp. motor; an 8000 g. p. m. (11.52 m. g. d.) pump connected to a 125 hp. motor; and a 12,000 g. p. m. (17.3 m. g. d.) pump connected to a 140 hp. motor. Provision is also made for the installation of a fourth pump and motor when necessity warrants it.

Between the two larger pumps is located a 300 hp. Sterling gas engine which may be connected with either of these pumps by a chain drive and clutch, thereby guarding against interruption of service in the event of loss of electric power.

The two smaller pumps may be operated automatically or by hand. They are provided with float switch controls so that they will start and stop automatically when the sewage in the suction chamber passes above or below certain levels. Should the sewage flow exceed the capacity of the two smaller pumping units, the high water bell alarm indicates when the largest pump is to be started. This 12,000 g. p. m. pump is connected to a variable speed motor permitting a discharge as low as 4000 g. p. m. It is operated by hand.

Each pump discharge is provided with a gate valve and a Dorr pivot valve. The pivot valve serves as a check valve and operates automatically; it may also be operated by hand.

A sewage level indicator is conspicuously placed in the pump room showing at all times the level of sewage in the suction chamber.

Vacuum System.—The pumps are primed with duplicate units of the Nash Hytor rotary vacuum pumps with a vacuum pump and a suction riser. The pumps are automatically primed when the vacuum drops to 15 inches. A Builders Iron Foundry venturi meter is located on the pump floor with bypass provided around this meter.

Switch Boards.—The switch boards, located in the pump house, are of the removable truck type and comprise eight trucks manufactured by the Condit Electric Manufacturing Company. Two of the trucks are on the incoming power lines: one is the instrument truck; one is a 440-volt truck to operate the motors in the screen house, the ejectors and the detritus tank plows; and four trucks control the pumps, one for each of the pumps with a spare for an additional pumping unit.

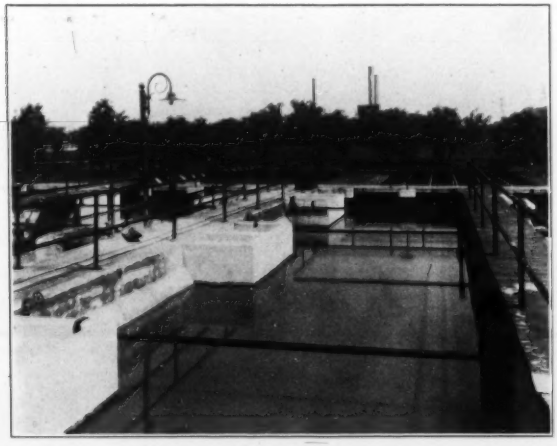

FIG. 2.—Surface of Imhoff Tanks.

Deritus Tanks.—Two deritus tanks, each 30 ft. in diameter and 21 ft. deep, are provided with two wooden booms for skimming purposes and with Dorr mechanism for collecting settled solids. The tanks are designed for a 15-minute sedimentation period.

Screen House.—In the screen house are two 2000 g. p. m. motor-driven centrifugal pumps. These pumps raise the settled solids in the detritus tanks to two fine screens (Dorr) in the screen room. These screens are 5 ft. in diameter and have $^1/_8$-in. slots. The screenings are picked up by bucket elevators and deposited in hoppers, from which they are

taken for pressing and final burial. The press is manufactured by the Hydraulic Press Manufacturing Company. In the future the solids will be burned in the incinerator, which is also located in the screen house.

Imhoff Tanks.—There are six Imhoff tanks, each 75 by 65 ft. in plan and 32 ft. deep. They are designed for six months' sludge storage capacity at 3.4 cu. ft. per capita, and with an average sedimentation period of two hours. Provision is made for reversal of flow. Our practice is to reverse the flow every 15 days. The tanks are so built that gas collecitng apparatus may be installed when desired. Sludge is removed from the tanks by gravity to the sludge drying beds or to the ejectors.

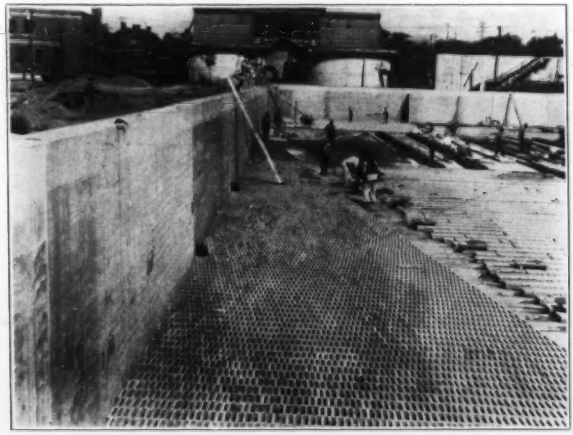

FIG. 3.—Floor of Trickling Filters under Construction.

Spray pipes encircle the sludge compartment for flushing the sides. Six sludge inspection chambers are built in each tank to permit the operator to observe the character of the sludge as it is being drawn from the sludge compartment. Piping is also provided for the removal of scum.

Ejector House.—In the ejector house are located two ejectors with a capacity of 50 cu. ft. each. They automatically alternate in filling and discharging, the time required being one-half minute for each operation. A dry-feed lime machine connects with the ejectors for the adjustment of the pH of the sludge.

Chlorinating House.—The chlorinating house contains three Wallace

& Tiernan vacuum type chlorinators. Chlorine is purchased in one-ton cylinders and is stored on cradles outside the building, from which point it is piped to the chlorinators.

Sludge Beds.—There are 3.38 acres of sludge beds designed for 7 applications per year during 10 months of the year. The beds are divided into 68 compartments, each 18 by 80 ft. Each bed has 13 in. of graded gravel and 9 in. of graded sand.

Additional Construction.—Litigation over the award of a contract has delayed for more than a year the construction of the sprinkling filters and humus tanks. Five acres of sprinkling filters and four humus tanks are to be constructed. The tanks are to be 70 ft. in diameter and 10 ft. deep.

The contract for 115,000 tons of stone for the sprinkling filters at $1.14 per ton, or a total of $131,000, was recently awarded.

The contract for the concrete work and piping on the sprinkling filters and humus tanks was awarded June 19, 1931, at $375,784. Work on these units will commence immediately and the plant is to be completed in about 18 months.

It is of interest to know that the delay of a year, caused by the litigation, saved the city $209,811 on these two contracts.

Results of Operation

The plant was put in service November 29, 1929. The daily average sewage flow in December, 1929, was 1.95 m. g. The sewage flow has gradually increased to a daily average of 3.3 m. g. in May, 1931. The smallest pump has a capacity of 5.76 m. g. d. and it is obvious, therefore, that we are compelled to operate intermittently. The sewage builds up in the suction chamber and trunk sewer to a definite elevation, when the pump starts. When the lower level is reached the pump is stopped. Due to the intermittent pumping the results of the analyses of the sewage may not represent its true character because of the difficulty of getting representative samples.

The sewage enters the suction chamber and passes through the bar screens, where the coarse material is removed. The average amount of solids removed by the screen is 0.5 cu. ft. per m. g. A recording sewage-level gauge, located in the office, shows the sewage level on each side of the screen thus indicating when the screen should be cleaned.

The pumps lift the sewage from the suction chamber through the venturi tube to one of the detritus tanks and thence to the Imhoff tanks. The detritus tank plows and pumps are put into service once a day for a period of 45 minutes and the accumulated solids pumped to the Dorr screens. The screenings amount to a daily average of 5.07 cu. ft. per m. g. and are pressed to 3.09 cu. ft. per m. g. The skimmings from the detritus and Imhoff tanks are removed daily by hand with wire sieves and amount to 0.39 cu. ft. per m. g.

The pressed screenings and skimmings are buried. No difficulty has been encountered with grease and oil. The incinerator for the disposal of screenings and skimmings was operated for only a few days for test purposes. It worked satisfactorily, there being no smoke or odor.

Imhoff Tanks.—The first Imhoff unit was put in service November 29, 1929, followed by the second unit December 15, 1929. These tanks were kept in service until May 15, 1930, and June 6, 1930, respectively, at which time they were taken out of service because of violent foaming. No attempt was made to control this foaming as we still had four unused tanks available. Tank 1 was substituted for Tank 2, which was taken out of service. This tank was not seeded. Tank 4 when started was seeded with sludge from Tanks 2 and 3, which were foaming.

The frothing over from the gas vents was so intense in Tanks 2 and 3, when they were taken out of service, that there was an accumulation of scum 1 foot thick in the settling compartment. To correct this unsightly condition, the liquid in the tanks was drawn down 6 feet and the tanks then allowed to remain idle. Three weeks after taking these tanks out of service, frothing ceased and the scum in the settling compartment settled after hosing. The sludge was kept in these tanks until August, 1930, when half of it was drawn to the sludge beds, the remainder being similarly removed in September.

The amount of sludge applied to the drying beds was approximately 40,000 cu. ft. The sludge drained rapidly and was removed in from 14 to 20 days. It was characteristically well-digested sludge. It was used by the Allentown Park Department and a farmer, both reporting good results. The sludge contained 88 per cent moisture when applied and 48 per cent when removed from the beds.

Tank 4 being seeded with foaming sludge, naturally started to foam within a few days but was controlled by hosing the gas vents. Six weeks after starting this tank, the foaming stopped. It has been in continuous service to date and has operated normally.

Tank 1 was started May 15, 1930, without seeding. It started to foam August 12 and continued to foam until September 18, 1930. Hosing kept the foam under control. This tank was taken out of service June 5, 1931, after removing 4 ft. of sludge for seeding Tank 2. This tank contains approximately 37,000 cu. ft. of sludge which will be withdrawn, after the proper rest period, to the drying beds.

Tank 4 contained approximately 45,000 cu. ft. of sludge June 4, 1931. Four feet of this sludge was transferred to Tank 2 for seed. Tanks 2 and 4 are in service at the present time.

The pH of the sludge in the normally functioning tanks was 6.8 to 7.0. The sludge transferred from Tanks 1 and 4 into 2 for seeding was treated with 1500 lb. of hydrated lime. The pH of this sludge was thereby raised

to 7.2. This was done for the purpose of a comparative study of the sludge at different pH values.

An experimental gas collecting dome and a gas meter was placed over one of the gas vents recently, for the purpose of studying the quantity and quality of gas evolved. Meter readings for a few days indicate that we may expect approximately 20,000 cu. ft. of gas from each tank. This amount would be quite sufficient to burn the solids removed from the sewage.

TABLE I

CHEMICAL ANALYSES—AVERAGES FOR 17 MONTHS

Parts per Million

Constituent	Raw Sewage	Imhoff Tank Effluent	Percentage Reduction	
Organic nitrogen				
Total	19.67	14.2	27.8	
Dissolved	8.56	7.61	11.1	
Suspended	11.1	6.59	40.6	
Ammonia nitrogen	16.09	16.21	Incr. 0.75	
Oxygen consumed				
Total	133	68	49.6	
Dissolved	47	38	19.1	
Suspended	86	30	65.1	
Residue on evaporation				
Total	653	465	28.8	
Loss on ignition	395	262	33.7	
Fixed residue	258	203	21.3	
Dissolved solids				
Total	413	405	1.93	
Loss on ignition	210	210	0.0	
Fixed residue	203	195	3.9	
Suspended solids				
Total	240	60	75.0	
Loss on ignition	185	52	71.9	
Fixed residue	55	8	85.5	
Chlorides as Cl	46.5	45.8	1.5	
Alkalinity as $CaCO_3$	208	217	Incr. 4.3	
Iron as Fe	2.5	2.1	16	
Settling solids cc./l	9.1	0.5	94.5	
Oxygen demand (B. O. D.)				
(July–May, inc.)	207	95	54.1	
			Chlor.	Chlor.
(July–May, inc.)			83.0	59.9
Bacteria per cc. agar at 37° C.	713000	328000	114 53.9	99.98
B. coli per cc.	66000	40000	4.2 39.3	99.99

The effluent from the Imhoff tanks passes to the chlorinating house and thence to the Lehigh River. Three miles downstream the City of Bethlehem Water Works are located, making it mandatory that strict attention be paid to the chlorination of the effluent. By the application of 40 lb.

of chlorine per million gallons of sewage or 4.86 p. p. m. we were able to discharge an effluent into the river containing an average bacteria count of 114 per cc. at 37° C. with 4.2 B. coli per cc. Bacteriologically this was better than the river as it enters the city. The percentage reduction of bacteria after chlorination was 99.98 per cent, with a 99.99 per cent reduction of B. coli.

The Imhoff tanks reduced the biochemical oxygen demand of the sewage 54.1 per cent, whereas the chlorinated effluent showed a 59.9 per cent reduction.

Cost

The total cost of the new plant, when completed, will be approximately $1,500,000.

The plant operating personnel consists of a chief operator, three operators, three assistant operators and occasional miscellaneous labor. The total cost of operation, exclusive of interest charges and depreciation, in 1930 was $22,014. The cost per million gallons of sewage treated was $24.85 as against the 1924–1925 cost of the old electrolytic-lime plant of $50.70 per m.g.

The cost per million gallons of sewage treated will, of course, decrease as the volume of sewage increases to the capacity of the plant, since the cost for labor will not increase materially with the increase in flow.

Conclusion

In the past the island was used for truck farming, then as a piggery for the disposal of garbage and later it was a jungle of weeds. Today a winding macadam road leads to the various units of the disposal plant, well kept lawns skirt the road and a newly planted hedge, shrubs and trees are converting the island into a place of beauty.

Excreta Disposal Plant of Kyoto, Japan*

BY S. NISHIHARA, C.E.

The Kyoto excreta treatment works was built in 1928 and has been in operation since the spring of 1929. The excreta from the unsewered district has been transported to the plant by motors and wagons, and amounts to about 9500 gallons daily from 40,000 population. It was decided to treat it by the activated-sludge process after diluting the excreta with well water or sewage.

The following installations were adopted:

A. Biolysis tanks (similar to Imhoff tanks).
B. Surge chamber to prevent scum in the biolysis tanks.
C. Wet well, receiving effluent from the biolysis tanks, with which is mixed return sludge from the final settling tank.
D. Machine room for blowers and pumps.
E. Aeration tanks of spiral-flow type, using diffused air.
F. Final settling tank.
G. Disinfector.
H. Contact tank.
I. Sludge-digestion tank.
J. Sludge-drying beds.
K. Sludge pump house.

In designing this plant, two essential points were considered: first, that the excreta occasionally arrives at the plant in a very fresh condition, and must be permitted to become slightly septic before treatment in the aeration tanks and, second, because of this preliminary tank treatment preceding aeration, means must be provided for preventing rapid accumulation of scum in the pre-treatment tank due to lack of heavy solids. The final decision was to adopt, in addition to the aeration tanks, the "Biolysis Tank" devised by us, and shown in Figure 2.

The excreta is first dumped into the tank (A), where it is diluted with 10 parts of water to 1 of excreta. The effluent from (A) is again diluted at the inlet to the aeration tank with 28 parts of water, the total diluting water thus amounting to 38 times the volume of matter to be treated.

Biolysis Tanks (A)

There are two biolysis tanks and each tank has two compartments, comprising the sewage chamber in the upper compartment and the digestion chamber in the lower. There is a surge chamber annexed and water jets are provided above the water surface of the tanks to break down the scum during the night when the excreta feeding is stopped. The excreta

* *Courtesy of Dr. Willem Rudolfs, New Brunswick, N. J.*

is dumped through the cylindrical tube at the middle of the tanks, where, diluted with water flushing through the spouts provided around the inlet, it flows down into the top part of the sludge-digestion chamber. The diluted liquid mixes with the septicized contents in the lower compartment, depositing the greater part of its solids, then flows up through the slot between the feeding cylinder and the suspended sloping baffles to the

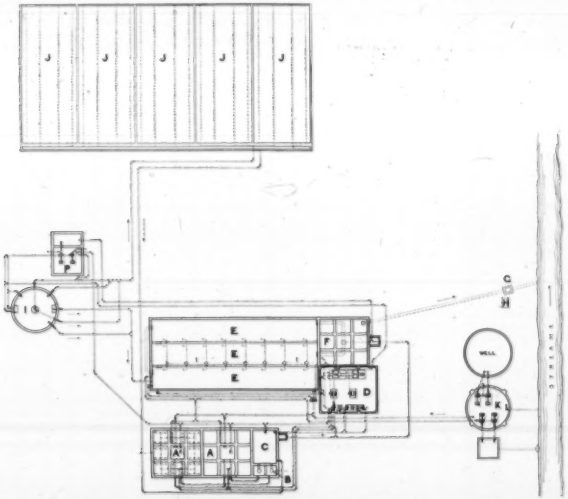

FIG. 1.—General Arrangement of Excreta Disposal Plant of Kyoto, Japan.

A. Biolysis Tanks (Similar to Imhoff Tanks)
B. Surge Chamber
C. Wet Well
D. Machine Room for Blowers and Pumps
E. Aeration Tanks
F. Final Settling Tank
G. Disinfector
H. Contact Tank
I. Sludge-Digestion Tank
J. Sludge-Drying Beds
K. Sewage Pump House
P. Sludge Pump House

effluent compartment. The partly clarified liquor enters the surge chamber (B), where duplex auto-siphons of 8 in. dia. and 14 in. depth are installed for the purpose of preventing scum because of the up-and-down motion of the water level, produced automatically by the action of the siphons. This device also permits free escape of gas. As the excreta is fed only during the day the action of the auto-siphon in (B) is stopped dur-

ing the night. Then the jets of water provided above the surface of each tank break up the scum.

Continuous operation of the plant would be desirable. A receiving tank was provided from which it was hoped to feed excreta uniformly and continuously to the tank (A). However, difficulty in obtaining an adequate

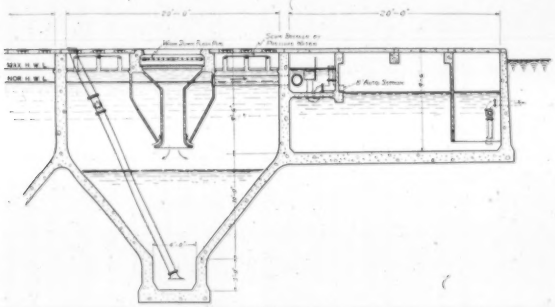

FIG. 2.—Biolysis Tanks and Sewage Chamber.

pump to treat such dense solids made it necessary to feed only during the day.

The liquid in the chamber (B) is discharged into the wet well (C) through the siphons, where it is mixed with return sludge from the final settling tank in the amount of 20 per cent of its volume (38 parts of water having been added to the excreta), and is lifted to the aeration tanks by the pump.

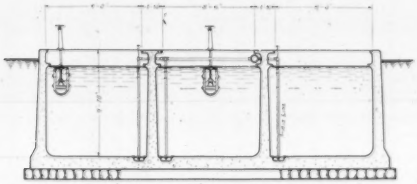

FIG. 3.—Aeration Tanks.

Aeration Tanks

There are three aeration compartments of spiral-flow type, similar in design and construction to American practice, as shown in Figure 3. They are provided with diffuser plates manufactured locally, set along one side

of each compartment. The plate area is about 10 per cent of the tank surface.

Air is furnished to the aerating units by two rotary blowers, one as standby, supplying air at the rate of 0.8 cu. ft. per gallon. The detention period in the aeration tank is 3 hours, with the inflow at peak load, which is somewhat shorter than the usual practice.

The liquid from the wet well is again diluted at the inlet to the aeration tank, as stated above, and when the feeding of excreta is stopped during the night, a small amount of sewage flowing near the plant is directly pumped to the aeration tank, thus taking the place of the excreta. In the initial operation, when the feeding of the excreta ceased, the aeration tank was circulating the activated sludge alone. Since these results were unsatisfactory, operation has been changed as described.

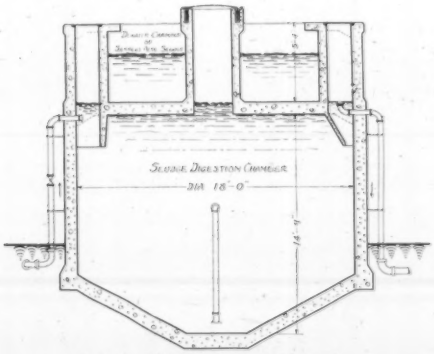

FIG. 4.—Sludge-Digestion Chamber.

Final Settling Tank

The final settling tank is of the Dortmund type, having a detention period of 50 minutes. The settled sludge is returned by gravity to the wet well (C) as return sludge, and surplus sludge is pumped to the sludge-digestion tank (I), where, after digestion with sludge from the tank (A), it is directly discharged to the drying bed (J). The final effluent from the tank (F) is sterilized in the contact tank (H) by a chlorinator, with chlorine applied at the rate of 2 p. p. m.

Sludge-Digestion Tank

The settled and partly decomposed sludge in the lower compartment of the biolysis tank (A), together with the excess activated sludge from the

final settling tank, is pumped to the digestion tank. The digestion tank is separated into two compartments, as shown in Figure 4. The upper compartment is provided mainly to dewater excess activated sludge by a short period of settling. Concentration facilitates drying on the sludge bed. The lower compartment is for the further digestion of the partly decomposed sludge from the tank (A), mixed with excess activated sludge or the sludge from tank (A) proper.

Two sludge pumps are installed in the pump house (P), for lifting sludge from both tanks (A) and (F). The pumps are also arranged to circulate the contents of the sludge-digestion tank once per day, in order to accelerate the digestive action. The gas collector is provided for future use at the center of the tank, and the displaced supernatant liquid from the digestion tank overflows to the aeration tank to be re-treated.

Results

The plant was in actual operation in April, 1929, and in September of that year sufficient activated sludge was present in the aeration tanks. At first, diluting water for the excreta was taken from the well on the property, but because of the slow development of the activated sludge in the aeration tank it was decided to dilute with sewage which contains much waste from dye works. Immediately after dilution by sewage, a rapid development occurred and adequate activated sludge was produced within approximately one month.

The plant has been operating at about two-thirds of its designed capacity. The average results are given in Table I, analyzed by the Health Department of Kyoto City, April 21, 1930. Table II shows the composition of the sludge as reported by the Tokyo Government Agricultural Experimental station.

TABLE I

	Parts per Million						
	"A" Tank	No. 1 Aeration Cham.	No. 2 Aeration Cham.	No. 3 Aeration Cham.	Final Settling Cham.	Effluent	Efficiency
Free and saline ammonia	15.0	9.1	15.0	9.0	6.0	6.0	60%
Albuminoid ammonia	39.0	12.0	9.0	6.0	12.5	12.5	68%
Nitrites as N	0.0	0.0	1.00	2.00	2.30	2.00	
Nitrates as N	0.0	0.0	0.66	2.00	1.53	1.20	
Oxygen absorption (4 hours)	12.25	0.96	0.96	1.09	0.43	0.66	95%
Number of bacterial colonies per cc.	208,000	2000	2000	22,000	500	200	
Endo's coli per cc.	240,000	4000	2400	40,000	1400	1000	

TABLE II

	Total Nitrogen	Phosphoric Acid	Potassium	Water Content, %
Surplus activated sludge	3.80	4.39	0.69	9.82
Sludge from "A"	1.89	1.64	0.45	17.63
Sludge from "A" (with 20% of activated sludge)	2.85	2.68	0.62	7.84

No difficulty has yet been experienced in producing approximately the above degree of purification at two-thirds capacity, but at full capacity we could not expect a uniformly stable effluent, perhaps because of the insufficiency of the air volume and also due to the limited period of aeration.

On January 3 and 4, 1930, conditions were very unsatisfactory. At that time, owing to the new year's holidays, the feeding of excreta entirely ceased for three or four days, while the activated sludge was continuously re-circulated from the final settling tank. When dumping was again resumed after a few days the aeration tanks recovered to normal conditions.

These results indicate that for such a plant, continuous and uniform operation of the whole installation is preferable from both the viewpoint of purification and economy. We are now planning another excreta disposal plant of about five times the capacity of the Kyoto plant, adding a receiving tank with sufficient capacity to store one day's volume, from which the excreta will be pumped uniformly to the preliminary tank by special pumps.

The Practical Operation of Sewage Disposal Plant Units*

BY F. E. DANIELS**

Sewage disposal plants are composed of varied combinations of units, simple or complicated, depending upon the necessities of the local situation or upon some special hobbies of the designing engineer.

The first duty of the operator is to find out "what it is all about." Unless the operator understands thoroughly what each unit is expected to accomplish, he cannot work intelligently and good results will be obtained only by chance. This is particularly emphasized now, because failure to observe this all-important requirement will lead to a serious amount of useless labor; to the overlooking of many defects in the design and construction of the plant which could be easily corrected by the operator, much to the benefit to himself and to the performance of the units; and, what is perhaps most important, to the failure to observe that some units are not working properly thereby throwing an undue or excessive duty upon the units which follow.

Every machine is most efficient when each part performs its function in the proper manner. The various parts and their functions are described in order.

Pumps.—Little need be said concerning the management and care of sewage pumps, save the necessity for protection against breakage by the maintenance of a proper screen to exclude objects dangerous to the pump, and the necessity for easy access for opening and cleaning the pumps in case of stoppage. Otherwise, ordinary care and lubrication suffice.

Screens.—The coarse screen is at best a necessary evil and unless intelligently cared for often constitutes a nuisance. The resulting nuisance may be due to septic deposits in the screen pit or to the accumulation of foul screenings. This may be more apparent in plants handling the sewage from institutions and small towns than in those of large cities. Septic action in the screen pit can be materially lessened by proper design of a self-cleaning invert and the avoidance of dead corners. Dead corners can frequently be eliminated by the operator by filling in with concrete.

The clogging of the screen lessens the velocity of flow, allowing deposits to accumulate and putrefy.

Since the screen must arrest those things in the sewage which are not desired therein, and an accumulation of such substances hinders the flow, it follows that screenings must be faithfully and regularly removed. This

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may be accomplished by means of some mechanical appliance or by hand. In any case, the screenings should be carefully cared for and disposed of in a cleanly and sanitary manner, by burying, composting or incineration. It should be borne in mind what the screen is intended to remove, therefore, the screenings should not contain an appreciable quantity of feces; or other materials better taken care of and digested in the tanks. On screens cleaned by hand, the operator can often lessen his burdens by washing the screenings up and down with his rake, thus allowing feces to be broken up and the finely divided substances to pass into the tanks to be digested there, and then remove as screenings only those substances of a coarser and more stable nature.

The installation of fine screens is for another purpose—for removing all of the suspended solids possible. Such installations have mechanical equipment to handle the material removed. The necessity for the mechanical care and cleanliness of such an installation is apparent.

Tanks.—Sewage tanks are of various kinds and serve several more or less dissimilar purposes. Therefore, the purpose of each tank must be recognized and borne in mind.

The septic tank is intended to take everything that comes down the sewer, digest what can be digested, discharge a moderately clear effluent and turn out the remaining solids as sludge. Such a tank requires little attention except that at intervals it must be cleaned out. Much work and offensive odors will be avoided if the tanks are operated so as to allow a tank, when filled, to be cut out of service to permit the sludge to digest fully for from three to six months. During this time the scum should be broken up several times to hasten digestion. When the tank is needed, the contents should be thoroughly plunged up to enable the sludge to go out upon the sludge bed with the water, so as to avoid the necessity of cleaning out solids after the water has run away.

Settling Tanks.—Settling tanks give a fresher effluent than septic tanks because the solids are removed before septic action begins to contaminate the flowing liquids with products of decomposition. Such tanks must be carefully managed and either cut out at intervals for digestion, or the sludge must be transferred to a separate-digestion tank. The old practice of running undigested settling-tank sludge to sludge beds will produce a very slow drying sludge and quite likely cause serious nuisance.

Modern settling tanks equipped with a mechanical drag, such as the Dorr or Link-Belt, are becoming very popular and have certain definite advantages in some cases. In such tanks the flights are operated continuously or at frequent intervals so as to remove the deposited solids as rapidly as they settle.

Imhoff Tanks.—Imhoff or two-story tanks were quite the "rage" at one time, because they give a fresh effluent, and transfer, by gravity,

settled solids to the digestion compartment below the settling chamber.

The operation of Imhoff tanks is very simple when the right conditions prevail, it being necessary only to cut in or cut out tanks as needed, to reverse the flow occasionally to equalize the deposition of the solids, and to draw out sludge at intervals to make room for more solids.

But very often conditions are not so simple. Thick scum appears on the gas vents, which has to be broken up to make it settle down into the digesting compartment. And what is more troublesome, the tank may foam through the gas vents at a great rate. There has been so much discussion over the cause and cure of foaming in Imhoff tanks that it is dangerous for any one to give definite directions. In many cases an acid digestion appears to be associated with foaming and an application of lime, thoroughly mixed with the sludge, raising the pH to an alkaline reaction, has frequently proved very effective.

Sludge must be drawn at intervals to make room for fresh solids, but too much must not be drawn at a time or else too little ripe sludge will be left to balance the fresh incoming solids. Unfortunately it is sometimes necessary to draw out all sludge in the fall in order to provide storage space for the winter when the sludge beds cannot be used. Such a practice should be avoided when possible. In such cases glass-covered sludge beds, permitting sludge drying in inclement weather, often prove a remedy.

Separate-Digestion Tanks.—These tanks receive from the settling tanks the sludge to be digested. The operation consists in preserving a proper balance of ripe sludge to fresh solids, of maintenance of temperature in artifically heated tanks, of drawing off supernatant water and removing the sludge as digested.

Sludge Beds.—Unfortunately the weakest, and most undersized member of the sewage plant is the sludge bed.

Sludge beds should be of ample size, of ample depth, of proper material and well underdrained. If too small, the dose of sludge will be too thick and slow drying; if the bed is thin, the sludge will invariably work down into the underdrains, which will necessitate digging up the drains and rebuilding the bed; and if insufficiently underdrained, the bed will be sluggish and will clog.

The bed must be preserved in good condition by keeping it in a deep, porous condition with fine material, sand or fine cinders on top to prevent the sludge from working down into the bed. It must be thoroughly cleaned after each use, as a fresh dose should never be run onto old sludge on the bed. Much has been written about the production of good sludge *versus* bad sludge. Although you may want good, rapidly drainable sludge, you may not always have that kind to dry.

Poor sludge may be materially improved by the application of a solution of alum or ferric chloride to the sludge as it is drawn from the tank. Such

an application coagulates the colloidal suspensions in the sludge, thus releasing the water and permitting it to drain away.

When you draw sludge remember this: have your bed in good condition and know what kind of sludge you have to draw. Then do not put on the bed any more than will dry in a reasonable time else, much to your sorrow, your bed will be tied up under a sludge pond forever and a day. Several thin doses can be dried and removed from a bed in the time it takes to dry a dose too thick to drain properly. It frequently happens that just when a dose will not drain properly, the bed is urgently needed. This necessitates handling only partially dried sludge and this is a very costly and often a nuisance-producing process. In the use of glass-covered sludge beds, pay particular attention to ventilation. Water does not evaporate from a stoppered bottle.

The following table will give you an idea of the difference in amount of sludge to handle by the elimination of only a few per cent of water. Therefore our aim is the driest sludge that can be produced in the least time.

TABLE SHOWING THE VARIATION IN THE AMOUNT OF SLUDGE WHEN THE PERCENTAGE OF ITS WATER CONTENT CHANGES

Percentage of Water	Percentage of Solids	Relative Amount of Sludge	Percentage of Water	Percentage of Solids	Relative Amount of Sludge
0	100	1.00	85	15	6.66
1	99	1.01	90	10	10.00
2	98	1.02	95	5	20.00
5	95	1.05	96	4	25.00
10	90	1.11	97	3	33.33
20	80	1.25	97.5	2.5	40
30	70	1.43	98	2.0	50
40	60	1.66	99	1.0	100
50	50	2.00	99.1	0.9	111
60	40	2.50	99.4	0.6	166
70	30	3.33	99.5	0.5	200
75	25	4.00	99.9	0.1	1000
80	20	5.00	100	0	∞

NOTE: Since sludge is but little heavier than water, the above table will apply almost equally well to weight or volume.

Dosing Apparatus.—In large plants dosed with butterfly valves or by means of mechanical distributors, little need be said as to the need of care, for such need is evident. But such devices as the air-locked siphon or the more complicated air-locked sewage feed-and-discharge apparatus should be thoroughly understood. It is too long a story to describe the action of all of them, but it is not difficult for you to learn all about the type you have to manage. There are at present only a few styles of siphons and feeds on the market, although the alternating, rotating, timed and twin ap-

paratus are quite interesting and ingenious. I learned a great deal about such devices by building and watching the operation of glass models.

Trickling Filters.—It must be borne in mind that the action of the trickling filter is practically continuous, and that there is no necessity for the long intervals of time between doses frequently noticed. The maximum rate should not be exceeded. This may vary somewhat according to the character of the sewage and depth of bed, but about 2 million gallons per acre per day is the usual good practice.

Since the dose must be applied so as to trickle over the surfaces of the broken stone or slag of the bed in thin films, it follows that even distribution over the filter must be maintained. This is accomplished by proper design and care of the dosing apparatus and nozzles.

Parts of the bed undosed do no work while other parts may be seriously overtaxed. A partially clogged nozzle or a small leak in a pipe will show bad effects at the underdrains.

The underdrains should be accessible and should be kept cleaned out to prevent accumulations of sludge, worms or other materials which decompose and spoil the effluent. A bright, sparkling or green algae condition at the underdrain outlets indicates good performance of the filter, while foul, greyish or fungi conditions at the underdrains indicate a bad nozzle, a leak, ponding or overloading.

Occasionally the growths of *oscillaria*, a blue-green algae so frequently seen on trickling filters, may be tolerated; but generally this growth must be kept down or else serious ponding will occur. The application of chloride of lime occasionally, either to the dosing tank or sprinkled over the surface, has been very effective in keeping beds free from growths. Ponding is frequently caused by improperly settled sewage or too fine material in the trickling filter. Cutting out the bed for a short time, or lowering the rate by dosing less frequently, usually helps. Careful digging over the bed with pick or harrow is sometimes beneficial, but never punch holes with a crowbar to let the water down.

Passing the tank effluent through a screen about the size of fly-netting will save much work in caring for the nozzles, by removing match sticks, unsettled patches of fungus and similar objects which cause stoppages in the nozzles.

Contact Beds.—The dose on contact beds should be carefully regulated to keep the rates below the maximum allowed, to insure the proper rotation, and the proper times for filling, standing full and especially the rest period between doses. Contact beds accumulate solids to an enormous degree and must at times be cleaned. This is expensive because the stone must be removed to be washed. The provision, at one plant I know, to wash the contact beds in place by pumping creek water up through the outfall was, on the face of it, foolish to say the least. Everything that can

be done to lessen cleaning results in economy. Proper tank treatment to remove suspended solids is imperative and a straining filter, such as a barrier of fine cinders at the inlet to the contact beds, has proved invaluable. Surface distribution on contact beds is worthless notwithstanding its prevalence at one time. The fewer the doses per day in contact beds, the better, and certainly not more than four are desirable.

Sand Filters.—Sand filters are excellent areas upon which to treat sewage. Under proper conditions they give by far the best effluent of any single process except perhaps broad irrigation.

In order to get good results it is imperative to have sufficient area, a sufficient number of beds to provide for proper sequence in dosing, perfect distribution and adequate underdrainage to get the effluent away as soon as the dose gets through the bed. The operator will be required to see that the sand is kept clean and in a porous condition, that the bed gets an even dose, that the dose is cut off completely at the proper time without the continuation of a dribble, that the dose disappears into the sand quickly, not more than one hour after it has been cut off and that the next dose follows not earlier than 12 or better 24 hours thereafter. Long intervals of rest between doses are beneficial; but standing full of sewage is fatal.

I was once asked by an assistant engineer to explain the difference between the action of a trickling filter and a sand filter. I told him that a man could walk the streets all day in the rain, but if he fell overboard he must soon come up for air.

Broad Irrigation.—The oldest of all processes of sewage disposal may be passed over because it is now necessary to conduct the sewage so far to find a suitable area that the process is going out of favor.

Disinfection.—Discussion of the use of chlorine or other disinfectants, odor preventives, fly exterminants and what not, is too broad a subject for my limited time. The judicious application of chlorine availeth much, but do not expect too much. It is not a substitute for biochemical processes.

The operator's chief care is to keep the apparatus going all the time and not let the supply of chlorine run out.

Activated Sludge.—This is still a special process although such plants are beginning to be more common. I can only advise those of you who may be connected with activated-sludge plants to make a special study of the various principles and steps in the process. The dewatering and disposing of the sludge constitutes quite a problem in itself.

Tests and Records.—It is most important that the operator have clear, concise and accurate records of the performance of his plant. This may save him his job, or save his town an expensive lawsuit.

We have said that the operator must keep his plant going properly, and must know just what the plant is doing; but that is not all. He must

have the data to prove to others, at some later date, what went on. This can be accomplished by faithfully making the prescribed tests laid down for him for his reports, and keeping a daily log of all activities and occurrences at the plant.

In making tests, care should be used to understand what each test is for and how it is done. Many, many times the operator laboriously makes daily tests at various places in his plant without knowing why. Many of his tests have been utterly worthless because done at the wrong places or improperly performed. Instructions are frequently given by an inexperienced or incompetent state inspector with the results that the operator is overworked, a mass of worthless data placed on file and nobody is the wiser. A competent operator will watch such instructions and remind the inspector to make himself understood. I could recite many instances to illustrate this.

Summary

I shall endeavor to sum up the high spots of this discussion:

Pumps.—Keep them clean and in order to run.

Screens.—Keep clean. Prevent nuisance from deposits or accumulations or scattered screenings.

Tanks.—Purpose (1) to separate solids from liquids, (2) to digest solids. Operate in series or in parallel, whichever gives best effluent. Watch pH reaction and digestion. Draw sludge frequently but carefully; know the condition of the sludge, adjusting with alum or iron if desirable.

Sludge Beds.—Keep clean, porous, with fine top layer on deep filtering media, well underdrained. Dose thin and dry quickly.

Dosing Apparatus.—Keep in order and see that the action is positive and certain.

Trickling Filters.—Secure perfect distribution, clean nozzles, have no leaks or weeps, clean underdrains, permit no surface ponding.

Contact Beds.—Have positive doses, low rates, rotation of beds, maintenance of proper cycles of filling, standing full, emptying and standing empty. Pre-straining of influent is very useful.

Sand Beds.—Require adequate area, clean surface, perfect distribution, adequate underdrainage, rapid and clear-cut doses and intermittent use.

Disinfection.—Keep in operation at all times.

Tests and Records.—Keep daily and faithfully.

General.—Keep the plant cleanly in all its parts, the surroundings attractive and everything in a condition to excite favorable comments from visitors.

Routine Tests for Operation of Sewage Treatment Works*

BY C. F. WERTZ**

The routine procedure followed at any sewage treatment works depends to a great extent upon the personnel and equipment available. The equipment, in turn, depends primarily upon the size and type of the treatment works.

Large cities usually employ technically trained men, chemists and engineers to supervise the operation, and in most cases a completely equipped laboratory is available. The other extreme is the ever-increasing number of small borough sewage treatment works, and the still smaller institutional sewage works, which have no trained operators and where laboratory facilities are meager or entirely lacking.

It is intended to set forth here information for the average operator who is neither a chemist, bacteriologist or engineer. Some of the more complicated tests will be mentioned but methods and technique will be omitted, it being assumed that where such tests are made there will be regular plant chemists who are familiar with these tests.

The greatest incentive for the average operator to establish a regular routine is the requirement of the various state departments of health that daily records be kept of the operation of the various units of the works. Where such requirements are not in force, it would be well for the municipal or institutional authorities to require that such records of daily operation be kept. The designing engineer can be of great assistance in this respect by preparing an operating report form which will cover the processes of the particular plant.

In the past a good many designing engineers have neglected to take into consideration the matter of routine tests and have failed to provide in the plant layout for the space or equipment necessary for such tests. The average operator who takes an interest in his work can, with the proper facilities and instructions, make numerous tests which will indicate the efficiency of the treatment provided.

Tests and records are so closely related that it is well to set forth the things which the operator should record from day to day, such as sewage flows, temperatures, sludge depths, etc. The following records, applicable to all sewage works, should be made daily: sewage flow in gallons per 24 hours; air temperature; influent sewage temperature; and weather conditions.

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Air temperature and weather condition records are valuable in explaining sludge bed results, particularly open beds, and abnormal sewage flows. Air and sewage temperatures are especially helpful in determining heat requirements in separate sludge-digestion tanks.

To show the work done by the various plant units, the following tests should be made and records thereof kept:

Grit Chambers.—Volume of grit removed in cu. ft.; date of cleaning and method of disposal of grit.

Screens (Hand-Operated or Mechanical).—Volume of screenings removed in cu. ft.; times of cleaning and method of disposal of screenings.

Primary Sedimentation Units.—Test for settleable solids in influent and effluent with Imhoff cones, using a two-hour settling period. In order to make various sewage treatment works records comparable, the two-hour settling period is advocated, regardless of the detention period in the tanks. Imhoff cones are readily obtainable from any laboratory supply house. The cone holds one liter of liquid and is graduated at the bottom to record cubic centimeters of solids per liter of sewage. There is a tendency for the lighter solids to adhere to the sides of the cone so that a glass rod should be used at least once during the settling period to clear the side walls. Samples for this test should be obtained at the time of peak flow through the works. Although an exact test would require that the sample of the effluent be collected several hours after the sample of the influent, the time interval being the detention period, actually the two samples are usually collected at the same time. The samples, therefore, should not be collected early in the morning when the weak and more thoroughly settled night flows would be reflected in the effluent.

When laboratory facilities are available, the total suspended solids, as well as the organic solids in the tank influent and effluent, should be determined. Whether these tests be made daily or less frequently depends upon the time the operator has to spare. The equipment necessary for these tests includes a drying oven, analytical balance, Gooch crucible, filter asbestos, a filter pump and a burner.

A measured volume of sewage is filtered through the Gooch crucible, which is a porcelain crucible with perforated bottom. Before filtering, a mat of pure asbestos fiber is formed on the bottom of the crucible and the whole is then dried and weighed. After the sewage has been filtered through it the crucible is again dried and weighed. The increase in weight represents the total suspended solids, both settleable and colloidal. The difference in results between influent and effluent represents the settleable solids by weight. In these tests the effluent sample should be taken several hours after the influent, the time again being the tank detention period.

To determine the weight of fixed and volatile matter, the Gooch crucible

and asbestos mat must be ignited prior to its first weighing. By igniting again after the total suspended solids have been determined, the volatile or organic matter is the loss in weight due to ignition.

Where mechanical devices are employed to remove sludge daily from settling tanks, a record should be kept of the length of time such apparatus is run. For at least the first few weeks of operation, the above-mentioned tests should be made both when the mechanism is at rest and when it is running in order to determine the effect of its operation upon the ability of the tanks to settle out the solids.

Tank effluents should further be tested to determine the putrescible matter remaining and which will need to be oxidized, either in additional treatment processes or in the stream. For routine work the relative stability test with methylene blue, although not very accurate, is the best one available for the small plant. The biochemical oxygen demand test, although furnishing a great deal more valuable information, can be made only in the larger, well-equipped laboratories. The relative stability test consists of filling a 150-cc., glass-stoppered bottle with the sample to be tested, then adding 0.4 cc. of the methylene blue solution and incubating at 20° C. A constant temperature incubator is not absolutely necessary for routine work. Incubation at normal room temperatures is accurate enough for the great majority of plants. The methylene blue is decolorized when all oxygen necessary for stabilizing the putrescible matter is depleted. Putrescibility is rated inversely according to the number of days required for decolorization.

A record should also be kept of the amount of grease or scum removed daily from the tanks.

Trickling Filters.—Record daily the area in actual service, either in acres of stone or in per cent of total filter area.

Test the effluent for settleable solids: two hours settling in Imhoff cones, and also for relative stability with methylene blue. Total suspended solids and settleable solids by weight may be made as set forth for plain sedimentation, if time and equipment are available. Where trained personnel and laboratory facilities are available, biochemical oxygen demand tests and tests for nitrates should also be made.

Record the number of nozzles cleaned and the floodings or chemical treatments for control of the *Psychoda* fly.

Contact Beds.—Records and tests as set forth under Trickling Filters, except the record of nozzles cleaned.

Secondary Sedimentation.—Test the effluent for settleable solids and also for relative stability. Record amount of scum removed and times when sludge is drawn.

Intermittent Sand Filters.—Record the area or number of beds in service. Make relative stability test of effluent.

Chlorination.—Record the quantity of chlorine applied, both total and pounds per million gallons of flow.

Tests for residual chlorine should be made sufficiently often to assure the operator that the proper residual is being maintained throughout the 24 hours. Such tests may be required upon the effluents from various units of the plant or only upon the final effluent, depending upon the point of application of the chlorine.

The test for residual chlorine consists of mixing 1 cc. of orthotolidin reagent with 100 cc. of the sample in a Nessler tube, and allowing the solution to stand for at least 5 minutes. Any free chlorine present will react with the orthotolidin to give a color. Small amounts of free chlorine will give a yellow color; larger amounts will give an orange color. By comparing the color obtained with standards, the amount of free chlorine can be ascertained. Regular testing sets of the standards and orthotolidin reagent are readily obtainable from chemical supply houses.

It is important also to record the contact time, otherwise the residual chlorine test is of little value.

Digestion of Sludge.—The proper digestion and drying of sludge is one of the major problems of any sewage works operator. It requires skill to produce well-digested sludge with even the latest types of tanks but even the rather out-of-date, plain septic tanks can be made to produce a fairly well-digested sludge, provided they can be put out of service at intervals to allow the proper microörganisms to develop and do their work.

For any type of tank, records of the capacity available for digestion and the capacity actually in use should be kept, also the volume of scum removed from digester or from the gas vents.

A pH test of the sludge should be made once a week, and the temperature of digestion recorded. Numerous pH testing outfits are on the market. The dilution method is best if distilled water for dilution is available. Without this, the porcelain dish spot test may be used, although less accurate. The test consists of mixing a measured portion of indicator solution, usually bromthymol blue, with a measured portion of the sample or, in the case of sludge, to a sample of sludge diluted with distilled water. The resulting color is compared with color standards which, for the indicator mentioned, range from yellow to blue. The pH of well-digested sludge should range from 7.2 to 7.4.

In separate sludge-digestion tanks, where provision for heating and the addition of lime has been made, pH determinations tell the operator when to add lime, tell him the results of such lime treatment, and further indicate the progress made toward completion of digestion.

With separate sludge-digestion tanks, records should be kept of the mount of green sludge added each day from the settling tanks, the quanity and kind of chemical used to aid digestion, and when heating, of the

volume of circulating water, and of the temperature of the water entering and leaving the tank.

Record should also be kept of the quantities discharged to sludge beds and the dates. With separate sludge digestion, quantities discharged can usually be determined by the drop in level of the sludge in the tanks. With other types of tanks the quantity must usually be measured by the depth run onto the sludge bed. In doing this an allowance of from 15 to 20 per cent should be made to include the liquid which quickly drains into the sand on the bed.

The area of sludge beds in use, the time sludge remained on the beds, date of removal, thickness of cake and volume handled reported as pounds of dried sludge at 110° C. should be recorded.

The content of solids in the digested sludge as discharged to the beds and in the dried sludge as removed from the beds should be determined each time sludge is discharged or removed. The content of solids in the fresh sludge should also be determined occasionally. If green sludge is removed daily from settling tanks to digesters, the percentage of solids in this sludge should be determined at least once a week. All of the results should be reduced to quantity on a dry basis as this is the only reliable comparison.

In the proper digestion of sludge the volatile organic matter passes off as gas, leaving the mineral matter behind unchanged. The reduction in percentage of volatile organic matter, therefore, indicates the degree of digestion.

Apparatus required for this test includes a steam-bath or electric hot plate, a drying oven, nickel dishes and an analytical balance. Twenty-five or fifty cc. of the wet sludge in a weighed nickel dish is placed on the hot plate until fairly dry. It is then placed in the drying oven at 110° C. and finally cooled and weighed. This is repeated until the weight remains constant. Formerly the loss in weight was reported as moisture. Lately the procedure has been to report the result as the percentage of dry solids. After the dry solids have been determined, the solids are ignited in the dish to a dull red heat until all the volatile matter or carbon has disappeared. The dish is again cooled and weighed. The loss in weight represents the volatile or organic solids. For normally digested sludge, the volatile matter should be less than 50 per cent of the total dry solids, and preferably below 40 per cent. For testing the dried sludge a 10-gram sample is usually used.

When gas from sludge digestion is collected, a record should be kept of the volume produced daily and of the gas pressure at the meter. The carbon dioxide content of the gas should be determined at least bi-weekly. A complete gas analysis apparatus is readily obtainable from the chemical supply houses.

Activated Sludge.—An activated-sludge sewage works is somewhat of a

luxury for the small town or institution because to obtain proper results a technically trained chemist or sanitary engineer should be in charge. There are no activated-sludge plants operating in Pennsylvania at this time, but one is under construction and several are in process of design.

Preliminary and final settling tanks should be handled as previously described. Records and tests of the activation process should include the following: actual aeration period based on net sewage flow; air used per gallon net sewage flow, or power used per 1000 gallons in the case of mechanical aerators; quantity of sludge returned; mixed liquor, volume settled in one-half hour in per cent; mixed liquor, dry solids by weight in per cent; dry solids in returned sludge by weight in per cent.

As the whole object in treating sewage is to protect the stream receiving the effluent, the actual purity or condition of the stream both above and below the sewage works should be determined periodically as part of the routine. Here again, the biochemical oxygen demand test and also the dissolved oxygen test will give the greatest amount of information, but for the average operator the relative stability test will suffice.

As previously stated, the trained chemist can make numerous additional determinations which are of value in plant operation, in sewage treatment research and in comparing results with other plants, but these determinations have no place in this paper.

In closing, it may be of interest to give a brief description of the laboratory facilities provided at the Middletown, New York, sewage treatment works—a plant designed for a normal daily dry weather flow of 3.5 million gallons. This is a separate sludge-digestion plant, providing for gas collection from heated digestion tanks fitted with steel floating covers. This plant was designed by the firm of engineers with which the writer is connected.

In designing the service building for this plant, an "L" shaped room, having a floor area of about 142 square feet, was set aside as the laboratory, and contract drawings and specifications called for a sink; a work bench around the sink and along the two windowed sides of the room, with drawers and storage space below; and a separate cabinet for holding chemicals and glassware. The specifications further required that the contractor include $500 in his bid for buying laboratory equipment according to a list to be furnished by the designing engineers. Actually the laboratory equipment complete, including glassware and chemicals, cost approximately $425. Some of the larger pieces of equipment, including items mentioned earlier in this paper, are as follows:

4—Imhoff cones	$12.60
1—Thelco electric drying oven	75.00
1—Electric hot plate	10.80
1—Gas testing apparatus	22.00

1—1/2 Gallon Barnstead water still (electric)	$42.00
1—LaMotte sludge testing set	30.00
1—Enslow chlorine comparator	12.50
1—LaMotte daylite comparator lamp	7.50
1—Students balance—Central Scientific Co.	67.75
1—Triple beam balance 1/100 to 100 grams	15.75

The cost of the laboratory complete, not including any general building costs, was about one-half of one per cent of the total cost of the sewage works.

The operator at this plant, although a non-technical man, is making most of the tests previously described, after having received instructions from a chemist of the designing engineers' office.

Finally, at existing sewage works without a building of some kind, the question of space and equipment for tests remains unanswered unless some type of building is erected. At those plants where the only building provided houses the chlorine equipment, it is too small in many cases for any other purpose, and the same problem is confronted. Apparatus for making the tests for settleable solids, relative stability and residual chlorine take up little room, so that a shelf or small cabinet is sometimes sufficient. For more detailed tests a separate room should be provided.

In the future, designing engineers should remember that it is much easier to provide for the laboratory in the original design and construction than to provide makeshift arrangements after the plant is built. Also that provision for a laboratory is really an initial plant cost, and furthermore that it usually is very difficult to obtain subsequent council appropriations for equipment or additions to a new plant.

Records for Sewage Treatment Plants*

BY EDWARD R. STAPLEY**

No business, company or corporation today would attempt to operate a business without records. In order to keep a set of books showing the condition and progress of a business, certain pertinent facts must be known. Sales and purchases are itemized. Income and expense items are classified by departments or by stages or steps in the process of manufacturing, construction, distribution, etc., as the case may be. By classification of accounts and the keeping of costs, each person in charge, from the foreman up through the department head to the general manager, is able to check the efficiency, to locate the apparent leaks or expensive steps in the business and to initiate steps leading to the cutting down or elimination of unnecessary expense, with resulting lowering of net costs.

In any business the mere keeping of records and the making of regular reports will result in an increase in efficiency. Any man worth keeping in a business will endeavor to have his records and reports as complete as possible and to have them show an improvement in the operation of the business as time goes on.

There is an analogy between the keeping of records in a sewage treatment plant and the keeping of books in a modern business. Scarcely a community in the state which has constructed a sewage treatment plant, with the object of reducing the pollution of watercourses and resulting nuisances, but has invested a sum comparable to the investment in the average (or leading) business concern in that community. Certainly, a business of this size cannot, and should not, be expected to operate itself without operating attention and supervision. Yet this has been the case in all too many instances. Treatment plants have been designed and constructed, the sewage turned in and the plants then left to operate themselves with all too unfortunate results.

Fortunately, this day is passing. Through increased knowledge and interest on the part of those in charge, many plants, formerly expected to run entirely automatically for all time, are now being given more or less regular and continuous supervision and attention. With this supervision and attention comes the need for recorded facts and data relative to the sewage and the operation of the plant.

Such records depend upon the use of certain tests and measurements. Equipment necessary for many of the more important tests will involve no large expenditure. The personnel available may be coached in the making

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of the simpler tests in laboratory instruction periods at short courses similar to this, or by special coaching. It might be stated, however, that few of the sewage treatment plants outside our larger cities have the personnel or equipment for this purpose which their cost and importance warrant.

A committee of the New England Sewage Works Association has given the following objectives for sewage treatment plant records:

1. Adequate records give an indication to the operator or local official in charge that the plant is or is not functioning effectively.
2. They stimulate the operator to pay increased and more intelligent attention to plant processes.
3. The collection of data will prove helpful to the operator in working out improvements.
4. The assembling of data will prove of value in protecting the community in lawsuits because of alleged pollution or nuisance.
5. A statement is provided for the public to indicate the manner of operation of the plant and to show that the public is receiving adequate returns for money expended.
6. The accumulation of data for the use of state or other supervisory officials will indicate the exact manner of operation and furnish a basis for judging the effectiveness of changes in the past or suggestions for the future.
7. A guide will be provided consulting engineers when called upon to design changes or additions to the sewage plant.

Data for sewage plant records fall under two main classifications: that pertaining to design and construction, such as would be given in an annual report, and that pertaining to quantities, tests and details of daily plant operation. In both of these classes, certain items will be general in nature for all plants, while others will be different, depending on the type of plant or steps in the treatment process.

Under "Design and Construction," we have such general data as:

Type of plant.
Basis for design, which includes the following:
    Estimated population to be served.
    Estimated per capita quantity of sewage, including average, maximum and minimum flows.
    Estimated character of sewage, including industrial wastes.
Point of discharge.
Date of completion and start of operation.
Date and nature of changes or additions to plant.
Total plant cost.

In addition, there should be items of a more specific nature relating to the number, dimensions, capacities, velocities and time periods for each unit in the treatment process. Other items which should appear in

monthly or annual reports include items of total operating cost, such as labor, supplies, power and repairs.

The blueprints or plans of the plant as built, with all changes and enlargements, should be a part of the records available for the plant operator or supervisor. I believe I would be safe in stating that in some Oklahoma cities no plans of the sewage treatment plants can be found.

Under "Daily Plant Operation" items of a general nature would include the following:

The weather, including the temperature of the air, direction and strength of wind and amount of rainfall.
Sewage flow, including total flow and max. and min. rates.
Length of time and amount of sewage bypassed.
Odors noticeable.
Hours spent at plant by operator and assistants.
Physical and analytical tests of sewage, such as temperature, settleable and suspended solids, relative stability, hydrogen-ion, B. O. D. and others.

Items applicable to particular treatment units would include the number of units in use, quantities of sewage, quantities and weights of sludge and screenings and when removed, depth of scum and how and when broken up, cleaning operations and when conducted, detention periods, direction of flow, rate of feeding and amount of chlorine, and additional items applicable to special features of the plant.

The New England Association committee report contains a detailed list of tests applicable to the various types of treatment. This report, however, does not contain any forms. Merely as a suggestion a monthly report form has been prepared (see opposite page) covering the record of daily tests and operating data for a common type of plant involving a bar screen, Imhoff tanks, trickling filters and sludge drying beds. With the exception of the B. O. D. determination, all of the data or tests called for in this report may be gathered or made with inexpensive apparatus and by any operator of reasonable intelligence with a small amount of coaching.

For plants of this type, located in the smaller cities, a form of standard sheet size, $8\frac{1}{2} \times 11$ inches, with margin punched for filing in loose-leaf notebooks, would seem most convenient and practical. With vertical columns ruled the short way of the sheet for the various items of test data and a horizontal line for each day of the month, a daily report on all items listed below may be made for an entire month by using only one side of the standard sheet. Forms of this nature may be printed or mimeographed at a very reasonable cost.

Great improvements have been made in the field of water works operation during the past few years. More or less complete records have been

proved to be necessary. Sewage treatment is noticeably far behind the water works. It will require time to change this condition. Competent and efficient operation of sewage treatment plants is just as much a municipal obligation as that of any other public utility. Continuous records and periodic reports will prove to be important aids.

The day is not far distant—in fact, it should be here now—when periodic reports on all water purification and sewage treatment plants will be required by all state boards of health.

REPORT ON OPERATION OF SEWAGE TREATMENT PLANT AT FOR MONTH OF 193

- Date
- Sewage flow, gal.
- Sewage bypassed, gal.
- Weather
  - Temp., ° F.
  - Rainfall, inches
  - Wind and direction
- Stream stage
- Screens
  - Times raked
  - Cu. ft. removed
- Imhoff tanks
  - No. in use
  - Dir. of flow
  - Depth of sludge
  - Sed. comp. skimmed
  - Slopes and slots cleaned
  - Gas vent solids broken up
  - Sludge drawn tank no.
  - pH of sludge
- Sludge beds
  - Dose in in., bed no.
  - Dry sludge removed in in., bed no.
- Filters
  - No. in use
  - Nozzles cleaned
- Settleable solids, cc. per liter
  - Tank influent
  - Tank effluent
  - Plant effluent
- Relative stability
  - Plant effluent
  - Stream above
  - Stream below
- B. O. D. plant effluent, p. p. m.
- Hours at plant
  - Operator
  - Extra help
  - Labor cost
  - Power cost
  - Supplies cost
  - Repairs cost
  - Total cost

Sewage Treatment Plant Beautification*

BY GEORGE M. MERRILL**

Of the infinite entities that are expected to yield beauty in some form or another, when given a proper landscape architectural treatment, the sewage treatment plant might seem less susceptible to beautification than almost any other structure. If this be true, the first question we should ask ourselves is this: "Can a sewage treatment plant be beautified?" The second question we should ask ourselves is this: "Should a sewage plant be beautified?"

Let us consider the first question by inquiring about the nature of beauty. True beauty depends upon more than merely the addition of so-called ornamentation. True beauty is always functional in some respect. Beauty, therefore, has been correctly defined as the effect of things expressing utility. The chief and fundamental beauty that may be given to any sewage treatment plant is to design the plant so that it may meet all its needs adequately and efficiently. If beauty has not been achieved by making ample provision for all the uses of a sewage plant, no decoration can save the plant from being a failure and a nuisance, and hence lacking in beauty.

One of the most discouraging problems which confronts the landscape architect is this: After the architect or the engineer has done his work—whether the work be good or bad—the landscape architect is consulted and asked to add beauty to the work of the architect or engineer at relatively little expense. Not until the designers learn the necessity for coöperating with the landscape architect, even in the inital stages of their designs, can the maximum landscape architectural beauty be realized in the projects with which these specialists are concerned. If beauty can be given to a sewage treatment plant, it can best be accomplished by providing a well designed plant, operated efficiently and economically under conditions which are sanitary, convenient and safe for those who operate the plant, as well as those who visit it. Indeed, the conditions which show cleanliness, care and order are the chief elements of beauty, and not misplaced superficial decorations.

Now let us consider the second question: "Should a sewage plant be beautiful?" After consideration of the first question, the answer to the second question must be obvious. If by beauty, we mean utility, convenience, safety, neatness and orderliness, our answer must be "yes." If by beauty, we mean, for example, such things as a bed of flowers on an open lawn of a sewage treatment plant, my answer is emphatically, "no."

For those people who go to a sewage treatment plant for work, study,

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business or curiosity, opportunity and comfort should be provided. To accomplish this, the grounds of the sewage treatment plant should be made as pleasant as they can be made, consistent with the primary use for which they are intended. On the other hand, the sewage treatment plant as it is designed and operated today should be as unobtrusive as possible. Its location and its general aspect should be such as to make it as little noticeable as possible. Modest trees and shrubs may be used with discretion, but certainly gaudy flowers or ostentatious shrubs or trees are as inappropriate as an attempt to make a lavatory a center of attraction by decorating it, or by calling special attention to it. We should recognize that a sewage treatment plant is designed primarily for the disposal of sewage and not for public or private recreation. There are other areas, such as parks, which are designed primarily for recreation, and it is only proper that these areas should be made literally attractive, but any attempt in elaborate or ornate displays to induce the pub ic to visit a sewage plant can result only in disappointment to all concerned.

As a preliminary study to the problem of sewage treatment plant beautification, I have made a survey by correspondence with men in every section of the United States, in order to determine the extent and character of the landscape development of sewage treatment plants in this country. I have visited the most important plants in Oklahoma. I have also studied reports on similar developments abroad. In these reports I find many different situations and conditions. For example, it seems that England has done more than any other country to make its sewage treatment plants orderly and attractive. The situation in this country is, I think, properly described by Mr. Arthur P. Miller, Secretary-Treasurer, Federal Sewage Research Association, in his recent letter to me when he says: "The tendency has been in recent years to give more thought to landscaping sewage treatment plants but water purification plants are still ahead." In Missouri there has been no attempt whatever to improve the appearance of the ground around the sewage treatment plant. In Arizona there is but one example where efforts have been made to make the sewage treatment plants attractive. In North Carolina several plants have been well planned and landscaped. In New England, many sewage plants are receiving attention to make them more attractive. In Maryland, New York and California, it appears from the very informative bulletins which the Sewage Works Associations of these states issue, that a great deal of attention is being given to making the sewage treatment plants in these states pleasant and agreeable. In Illinois, according to Mr. Gus H. Radebaugh, "practically every sewage treatment project that is constructed under the Sanitary District Act of 1917 is being properly landscaped."

While most of these reports are encouraging, I fear, after studying many photographs which have been submitted to me as illustrations of sewage

treatment plant beautification, that in many cases there is a misconception of what constitutes beautification.

If we should see a waitress or a nurse attending to her duties while attired in an evening gown, we could justly feel the impropriety of such dress, no matter how beautiful the girl, or even the dress itself might be. Such a dress would probably interfere with the proper performance of her duties, and present an example of bad taste. So it is with a sewage treatment plant. Any attempt to disguise the fact that it is a prosaic utility will probably interfere with its efficiency, and be no less offensive to people of good taste than the putrescible odor for which some plants are noted.

After my condemnation of so much that has been done and might be done for so-called beautification, you might properly ask: "How can a sewage treatment plant be beautified?" In order to illustrate more definitely just how a sewage treatment plant should be developed from the standpoint of landscape architecture, I have acted on a suggestion of Professor E. Stapley, and roughly sketched a proposed development for the plant here in Stillwater.

The solution which I offer for the problem here in Stillwater is not a panacea for all sewage problems. Nor is it even intended as a solution for all the landscape architectural problems of sewage treatment plants. The kind and size of a sewage treatment plant as well as the peculiar conditions of its location and operation are the factors which determine the kind of landscape development that should be followed. Every plant, therefore, is a different problem, and requires a different solution. Nevertheless, in every sewage treatment plant that is successfully developed from the standpoint of landscape architecture, the same general principles of design must be followed. The main objective should be to unify all parts of the design so that each part will be, as far as practicable, both useful and beautiful.

Sewage Sludge as a Fertilizer*

BY HORACE J. HARPER**

The value of sewage sludge as a fertilizer material will depend entirely upon its source. The two processes of sewage treatment most commonly used at the present time are the Imhoff tank and the activated-sludge process. Seasonal conditions will affect the composition of the sludge produced from either of these processes; however, the nature of the nitrogen content of the product is very different when the two materials are compared.

Activated sludge, which is produced as a result of the action of aerobic bacteria on the sewage, will contain approximately five or six per cent of total nitrogen and the total phosphoric acid content will be approximately three per cent. Sludge from Imhoff tanks seldom contains more than two or two and one-half per cent of nitrogen and the total phosphoric acid content will vary from one to two per cent. The amount of potash is negligible in each case.

I have had considerable experience with the use of the activated-sludge fertilizer, termed "Milorganite," which is being produced in large quantities by the city of Milwaukee. I have also examined many samples of sludge produced by the Imhoff tank process, although no fertilizer tests have been conducted with the latter material here at the Oklahoma Agricultural Experiment Station. Many comparisons of Imhoff tank sludge with other fertilizers have been made at different places in the United States and in foreign countries. In most cases the availability of the nitrogen content of this material is relatively low, but the effect on the soil exists for a considerable period of time, due to the slow rate of decay of the resistant forms of organic matter which remain after the digestion of the sewage solids. In studying the different experiments which have been conducted, the rate of application of sludge has been relatively high. In some instances 40 or 50 loads of sludge have been used per acre. This is not an excessive rate of application for soils on which truck crops are grown, but the rate of fertilization is very high as compared with the average rates of application of farm manure and commercial plant food.

Experiments conducted near Baltimore, Maryland, during the season of 1923, 1924, 1925 and 1926, in which ten tons of stable manure was compared with one thousand pounds of a 5–8–5 fertilizer (NH_3 : P_2O_5 : K_2O) and 20 tons of dry sludge and 40 tons of liquid sludge per acre, the stable manure was much superior in all cases. Potatoes, cabbage and sugar corn gave better response from the sludge treatment than spinach and tomatoes.

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** *Prof. of Soils, Oklahoma A. & M. College, Stillwater.*

The nitrogen content of the sludge used in these experiments varied from 1.56 to 3.19 per cent. Most of the values, however, were approximately 2.0 to 2.5 per cent, which is about the same amount of nitrogen found in dry farm manures. Other experiments near Baltimore were conducted using the air-dried sludge as a fertilizer for lawns; good results were secured. The rate of application was 9 cubic yards, or approximately 10 tons, per acre. Investigators at the Baltimore plant state that practically all of the sewage sludge produced at this plant could be used effectively on the lawns of the surrounding communities.

Another comparison of sewage sludge with other forms of fertilizer was conducted by the North Carolina Agricultural Experiment Station in 1928. Of all the sources of nitrogen used for the fertilization of cotton, sewage sludge was the poorest and sodium nitrate was the best. An experiment in Florida, conducted by members of the Florida Agricultural Experiment Station, demonstrated that sludge was an effective fertilizer for certain grasses and Japanese cane. In the following year after the sludge treatment was stopped, the nitrogen content of the roots and crowns of Napier grass was 3.5 times as high as the nitrogen in untreated plots, and the yield was 3.3 times as large as that on adjacent areas which were not fertilized with sludge.

An experiment conducted by J. F. Muller, of the New Jersey Agricultural Experiment Station, indicates that on many soils sewage sludge may require the addition of other fertilizers in order to produce the most satisfactory yields. The material used in his experiment was a dewatered raw sludge which was pumped from the plant to sand filter beds, where it was removed for use in the experiments. The dried sludge contained 10% water, 37% ash, 28% total carbon, 1.96% total nitrogen, 0.62% total phosphoric acid and 0.13% of potash. An experiment with beets, in which one hundred equals the yield of the unfertilized plot, resulted in an increase of 10 per cent in the crop when 10 tons of dried sludge were applied per acre. An application of a 5–8–5 fertilizer yielded 4380 per cent in comparison with the sludge treatment. The application of sludge reduced the yield of barley. The yield of corn with and without different fertilizers was as follows:

Treatment	Yield in Grams per Plot
None	12.85
Sludge	15.60
Sludge and phosphate	68.80

In another experiment in which the sludge was compared with and without fertilization on grass, the plots treated with sludge yielded as much as plots where minerals were also applied with the fertilizer. Mr. Muller recommends that 100 lb. ammonium sulphate, 200 lb. 20% superphosphate and 50 lb. potash be applied to each 1650 lb. sludge in order to prepare a balanced fertilizer. Applications of lime will be necessary in order to cor-

rect the acidity which develops in the soil from the use of sewage sludge over a long period of time.

Mr. O. J. Noer, who has worked with the Milwaukee Sewerage Commission, prepared a thesis on the value of activated sludge, under the direction of Professor E. Truog of the University of Wisconsin. His experiments indicated that the most effective use of sewage sludge was for lawns and golf courses. Most of you are familiar with this product and know that the major portion of the output is being used as a conditioner in the manufacture of complete fertilizers, where it also furnishes a part of the total nitrogen. There are many activated-sludge plants in the United States and a few exist in Oklahoma; however, the development of a market for activated sludge or sludge from Imhoff tanks has not been developed except by a few large plants. Milwaukee activated sludge was sold in 1929 for approximately twenty dollars per ton. Sludge from Imhoff tanks is usually sold for twenty-five cents to one dollar per load or ton, according to recent information from Dr. Willem Rudolfs. In the eastern part of the United States there are many truck farmers, and also the soils in that section are less fertile than those of western Oklahoma, consequently response is generally secured from the addition of nearly any kind of fertilizer material. In eastern Oklahoma, where the fertility of the soils in general is relatively low, sewage sludge derived from either the activated-sludge or the Imhoff tank process could be used to good advantage in the fertilization of those crops which require a considerable amount of nitrogen in their development.

The City Council of Schenectady, New York, passed an ordinance in 1915 offering to sell their sludge at ten cents a load, which was raised to twenty-five cents a load after the demand for it developed. Large, healthy tomato plants growing on the sludge piles convinced the farmers of the value of the material. The fertilizer was broadcasted in some cases at the rate of 10 to 15 tons per acre; in other cases it was drilled in rows or was placed directly in hills. Much of it has been used for greenhouse beds by mixing 30 per cent sludge with 70 per cent of soil.

In Madison, Wisconsin, the sewage sludge is digested for six months, after which it is pumped to the filter beds, dewatered and sold for fifty cents per cubic yard.

Experiments with this material have increased the yields of corn, potatoes, celery and tobacco. An analysis of the Madison, Wisconsin, product indicates that it varies from 2.5 and 3.5 per cent nitrogen, about 2 per cent phosphoric acid and from 0.1 to 0.5 per cent potassium oxide.

Wet sewage sludge is sometimes pumped to farm land, where it is distributed in rows and plowed under as soon as the material is dry. At Vineland, New Jersey, fifty acres of land, located 2.5 miles from a town of 8000 people, is being used to dispose of this material. The area selected was very

sandy and was covered with undesirable vegetation. During the first two years the farmer was paid a salary while the land was being cleared. Since that time the income from the land has been sufficient so that no salary has been paid, because the farmer has been able to sell enough produce from the land to make a good salary and cover the expenses of keeping up the farm.

Experiments comparing the value of dry sludge and liquid sludge indicate that the liquid sludge is considerably more valuable than the dry sludge. This is due to the fact that wet sludge loses soluble materials of fertilizer value when it is allowed to drain and dry on sand beds. Sewage irrigation is an old custom in Germany and in Scotland, and it has also been used to a limited extent in California, Colorado and Texas with varying success. One acre of land will absorb approximately 60,000 gallons of sludge annually. Grassland should be treated every four years. Most gardens can be fertilized each year.

Estimates have been made by some engineers to indicate that one acre of land may absorb the wet sludge produced by a population of from one thousand to four thousand. This rate will undoubtedly vary with soil conditions. One town in Texas uses six acres of land on which the sewage sludge is distributed from a plant having a daily capacity of 350,000 gallons of sewage.

The farmers of Europe and Asia have utilized sewage products for fertilizer for long periods of time, and there is an excellent opportunity for limited areas of land to be utilized more effectively in Oklahoma by the proper handling of activated and Imhoff tank sludges, which contain much valuable plant food, although the availability is low and the rate of application must be relatively high in order to obtain favorable results as a fertilizer.

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Sewerage System and Sewage Treatment Plant Village of Freeport, New York*

BY LAWRENCE L. LUTHER**

The village of Freeport is situated in Nassau County on the south shore of Long Island, 40 minutes from Times Square. The population is 19,475. Construction of a sanitary sewer system was taken under consideration in 1912, but installation was delayed until 1926. Today Freeport has a total of 28.5 miles of sanitary sewers varying in size from 8 inches to 27 inches; a modern disposal system consisting of pumping station, treatment works, outfall sewer and force main. The entire village will be sewered in the very near future.

Trunk Lines.—The present design provides for a contributory population of 42,000 people with a maximum flow of 250 gallons per capita per day. The trunk sewers are designed to carry this flow when running 0.7 full and the lateral lines when running 0.5 full. This per capita allowance for the maximum flow is high, but a large amount of ground water accounts for it. The present water consumption in the village is about 68 gallons per capita, or about one-quarter of the estimated maximum per capita rate of flow. The trunk sewers are designed for a connected population of about twice the present population of Freeport, with a maximum sewage flow of about four times the present average per capita water consumption.

Lateral Lines.—There are at present approximately 28 miles of 8-in. and 10-in. laterals laid in the village. Practically all the business and apartment house areas are sewered and a large part of the residential sections. These sewers were installed some time after the trunk sewers and treatment plants were built.

Clyde Potts, consulting engineer of New York, and Baldwin & Cornelius Co., Inc., of Freeport, were the designers of what we term the comprehensive district system.

Pumping Station.—The pumping station consists of electric motor-driven pumps automatically operated, installed in three separate units, each unit of 1.5 m. g. d. capacity. A concrete storage well of 30,000 gallons capacity is installed beneath the pumping station to balance the flow of sewage without backing up the sewage into the main sewers above the normal flow line.

The piping and valves are installed to take care of a flow of 10 million gallons per day, corresponding to a maximum flow of 250 gallons per

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** *Superintendent.*

capita for a population of approximately 40,000 persons. The pumps that are in use at the present time will take care of the flow from a connected population of from 10,000 to 12,000. The pumps are placed underground, are easily accessible and driven by 15-horsepower motors. These pumps are automatically controlled by the level of the sewage in the suction well. When the sewage rises to a pre-determined point one of the pumps cuts in. The second and third pumps automatically take care of increased flows. The order of the pumps is changed daily so that no one pump is used continuously. The pumping station is largely underground. The superstructure is built of brick and presents a very attractive appearance. The grounds are planted with shrubs and the passing public often wonders just what it is. In fact, on more than one occasion we have had inquiries from strangers as to whether the village wanted to rent that little brick building for a gasoline station.

The operation of this station is practically automatic. One operator visits it three times a day to clean the bar screens and to oil the motors. All screenings are trucked to the municipal incinerator and burned daily with the refuse. There are no odors, noises or other unpleasant features. In fact, we feel that it enhances the value of the surrounding properties.

Force Main.—The sewage is pumped to the treatment plant through a 24-in. reinforced concrete main approximately one mile in length.

Treatment Plant.—The treatment plant consists of settling tanks, chlorinating chamber, sludge-digestion tanks and two glass-covered sludge drying beds. The immediate construction is built to take care of a connected population of approximateiy 10,000 persons. Extensions can be made from time to time as required without interruption to the plant. The capacity of the plant is based upon an estimated average flow of 125 gallons per capita and a maximum flow of 250 gallons per capita.

The settling tanks are placed underground, constructed in two units with a capacity sufficient to give a detention period of four hours, with five per cent additional capacity for sludge storage. Tanks are covered with a concrete cover with sufficient iron doors to permit inspection and skimming. Sludge is removed through 6-in. sludge pipes located at the invert of the hopper bottoms of the tanks and pumped into the digestion tanks without interrupting the operation of the settling tanks. The settled sewage passes into the chlorinating chamber where chlorine is applied. After a detention period of approximately 30 minutes, it passes over a V-notch weir to the 30-in. outfall sewer, which terminates about 2500 feet from the plant. The sewage enters a manhole connected to a 24-in., cast-iron pipe equipped with four 24-in. by 12-in. diffusers; these empty into what is known as Freeport Creek. The settling tanks cover an area of approximately 50 by 60 feet.

The two sludge-digestion tanks, covering an area of about 25 by 55 feet,

are placed partly above ground. They are covered with a concrete roof with necessary openings. Capacity is provided for a connected population of 10,000 people upon the basis of 4.5 cu. yd. of sludge per million gallons and a storage period of 150 days. This amounts to 2.3 cu. ft. per capita. The sludge is pumped from the settling tanks into the digestion tanks, the liquor decanted and returned to the settling tanks. The sludge remains in the digestion tanks until it has been converted by bacterial action into a harmless and odorless residue which is removed about every three months, by gravity, to the sludge drying beds.

There are two glass-covered drying beds. These have a total area of approximately 5000 sq. ft. providing 0.5 sq. ft. per capita. They were constructed by the Lord and Burnham Company and are of their standard design. These beds consist of 4 to 6 inches of sand laid on 10 inches of broken stone. Tile drains with open joints are laid beneath the stone and the liquor returned to the drainage well under the head house, thence pumped through the decanting line back to the settling tanks. When sludge is dry and ready for removal, which varies from six to ten days in good drying weather, it is removed by hand from the beds.

A brick building 25 by 30 feet, known as the head house, houses the two gasoline-driven sludge pumps, chlorinating apparatus, Yarnall Waring V-notch flow meter and heating plant. The building is of an ornamental design and the grounds are attractively planted with shrubs.

All piping, outfall, sludge pumps, pumping station and head house have been designed to meet the ultimate requirements.

The treatment works and trunk lines were designed by Nicholas S. Hill, Jr., consulting engineer of New York City.

Costs.

Treatment plant	$116,330.00	
Outfall sewer and diffuser	24,487.00	
Force main	26,950.00	
Pumping station	34,355.00	
Total cost plant		$ 202,122.00
Trunk lines (10.5 miles)	$325,000.00	
1st district (17.5 miles)	333,809.00	
2nd district (10.75 miles)	175,000.00	
Total cost sewers, etc., to date		$ 833,809.00
Grand Total		$1,035,931.00

Operation.—Two men are employed in the care and operation of the sewage treatment works. A small, completely equipped laboratory has been installed for the making of analytical determinations necessary for the efficient operation of the treatment works.

Daily orthotolidin tests are made, Imhoff cone tests, pH determinations of the effluent, influent and sludge, and stability by methylene blue; the efficiency of the drying beds is watched very carefully by sampling the sludge daily and noting the daily loss of moisture. Sludge drawn to the beds is sampled and analyzed for moisture, organic and mineral content. We have experimented to determine how much the top ventilators and side windows of the glass enclosures should be left open or closed. Our experience has proved to us that in the summer months the top ventilators must be open at least 6 inches and side windows from 2 to 3 inches to stop sweating. In the winter months only the top ventilators are left open for about 1 inch. No sweating has been noted.

The temperatures of sludge in the settling and digestion tanks are taken daily, also the air temperatures. Wind directions are noted daily. A very complete daily log sheet is in use and all the necessary data concerning the operation of the plant is kept. This is of great value not only for the present, but in the future when the time arrives for extensions all the necessary data will be available.

A Yarnall Waring V-notch weir recording meter is located in the head house and works off the float chamber that also governs the chlorine machine. This enables us to keep an accurate record of the sewage flow.

Sludge is pumped to digesters three times a week at the present time. When more sewage is available sludge will be pumped daily. Sedimentation tanks are skimmed four times a week and all floating material broken up by hosing. Material in suspension, after hosing, is skimmed off and removed to the digestion tanks.

All four digestion tanks are well seeded and show a pH of from 7.0 to 7.4. The tanks are so arranged that the sludge is worked from Tank 1 through to Tank 4 and run from Tank 4 to the drying beds. At no time are the tanks emptied. As raw sludge is added semi-digested sludge is run into the other tanks.

No trouble has been encountered except some gasification in the sedimentation tanks. This has been overcome by more frequent pumping of the sludge. It has also been necessary to find a paint that would last on the inside of the tank covers and on the pipes immersed in the tanks. After trying many formulae, Inertol was tried and up to this time it has proved very successful. The iron work in the drying beds is now painted with aluminum paint.

Statistics, Sewage Treatment Plant

Type of sewage	Fresh, domestic
Industrial wastes	None
Total flow per year	114,219,200 gallons
Average daily flow	500,000 gallons

Total yearly screenings	317 cu. ft.
Total dry sludge removed from beds per year	58 cu. yd.
Population served	2500 persons
Total pounds of chlorine used per year	2958
Pounds chlorine per million gallons	47.78
K. W. per million gallons	69.35
Total cost per million gallons	$12.50

Includes, chlorine, power, supervision, maintenance, insurance.

Laboratory Determinations

Average residual chlorine (orthotolidin test)	0.4
Average percentage solids removed (Imhoff cone, 2-hr. setting)	97.3
Average pH of influent	6.4
Average pH of effluent	6.8
Average pH of sludge in digestion tanks	7.1
Average percentage of moisture in wet sludge	86.4
Average percentage of solids in wet sludge	13.6
Average temperature of influent	43°
Average temperature of effluent	47°
Average temperature of digestion tanks—summer	73°
Average temperature of digestion tanks—winter	42°
Relative stability of tank effluent	48

Industrial Wastes and Stream Pollution

Pollution and Recovery of the Mississippi River at and below Minneapolis and St. Paul

By G. J. Schroepfer* in consultation with J. A. Childs**

With analytical data covering practically a six-year period collected on the Mississippi River from the northerly limits of Minneapolis to Wabasha below Lake Pepin, a distance by river of approximately one hundred miles, it is possible to make some very interesting calculations and observations on river pollution and recovery. This paper presents a compilation of the analytical data collected on the river, as well as comparisons with the calculated results at several stations. An attempt has been made to determine the various factors involved in the pollution and recovery of the Mississippi River, such as oxidation of organic material in solution and suspension, and that deposited as sludge on the river bottom, dilution, sedimentation and re-aeration. The limitations of the calculations are discussed and explanations offered for the difference between the observed and calculated results. A brief general description of the river follows.

General Description of the Mississippi River

The Mississippi River has its source in the numerous lakes in northern Minnesota, its origin being Lake Fernando de Soto, located about 500 miles upriver from Minneapolis and St. Paul. From its source to Minneapolis the river flows almost exclusively through the glacial drift and receives the sewage from a number of small municipalities. As it enters Minneapolis the river, because of the processes of natural purification, is in a relatively clean condition. From Minneapolis and St. Paul until it leaves the state, the river flows in a rocky valley excavated in pre-glacial times. For the stretch of about 25 miles from where it enters Minneapolis to South St. Paul and Newport, where large packing plants are located, there exists a zone of degradation or pollution. Throughout the greater part of this reach, and continuing downstream to Prescott, Wisconsin, a distance of about 20 miles below South St. Paul and Newport, a zone of active decomposition obtains. At Prescott, the Mississippi is joined by the St. Croix, the diluting effect of which improves the river to some extent, so that a zone of partial recovery exists from this point downstream for a

* *Assistant Engineer, and* ** *Chief Engineer and Secretary, Metropolitan Drainage Commission of Minneapolis and St. Paul.*

distance of 19 miles to Red Wing. At this point the river widens to form Lake Pepin, which is about 22 miles in length, extending downstream to Read's Landing, where the Mississippi is joined by the Chippewa. This reach of the river is classified as one of almost complete recovery. Below Wabasha a zone of intermittent pollution and recovery exists in which the water, except directly below local sources of pollution, is in a comparatively clean condition and, to all appearances, has practically recovered from its burden of pollution.

The natural flow of the river has been changed by the construction of two dams. The Twin City Lock and Dam is between Minneapolis and St. Paul, and about 2 miles above the mouth of the Minnesota. The Hastings Dam, completed in 1930, is almost 30 miles below the Twin City Lock and Dam and about 4 miles above the mouth of the St. Croix. These dams so retard the current as to permit the deposition of sewage solids, which materially changes the effect of pollution.

Sources of Information

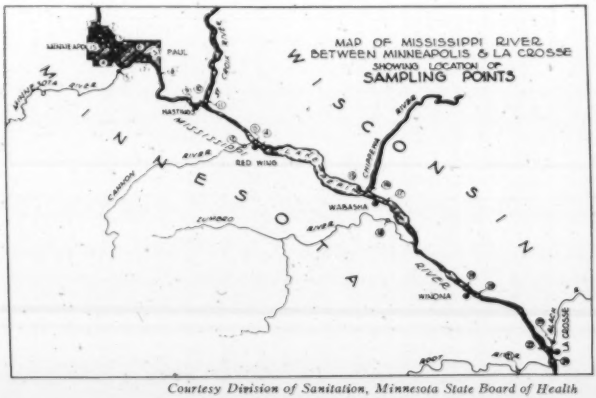
Investigations have been made by a number of official agencies, beginning with a study by the U. S. Public Health Service extending from June, 1926, to August, 1927. After a lapse of four months the Minnesota State Board of Health resumed the collection and analysis of samples in January, 1928, and continued therewith to January, 1929, after which in June, 1929, and thereafter, the work was again undertaken, this time by the Metropolitan Drainage Commission. This Commission was created by the Minnesota Legislature in 1927 to study and recommend ways of remedying the polluted condition of the Mississippi River, particularly as regards the pollution from Minneapolis and St. Paul. The stretch of the river studied is shown in Figure 1. The locations of the sampling stations, which, with but a few exceptions have remained unchanged during the course of the investigations, are also shown on this chart.

Samples were collected daily by the U. S. Public Health Service, and every two weeks by the State Board of Health. The Metropolitan Drainage Commission collected weekly samples from Stations 1 to 9, inclusive, and bi-weekly samples from there on downstream. Analytical determinations were made in accordance with the methods prescribed in "Standard Methods of Water Analysis" with minor modifications. Stream flow data have been obtained from the U. S. Geological Survey and the U. S. Engineer Office, St. Paul.

Sources of Pollution

During 1927 and 1928, determinations of the source and quantity of pollution were made by the State Board of Health for the smaller municipalities discharging into the stretch of the river considered, and by the

Metropolitan Drainage Commission for Minneapolis, St. Paul, South St. Paul and Newport. The population equivalent of the sewage and wastes discharged into the Mississippi River above Minneapolis, taking into account the reduction accomplished by treatment and the increase due to wastes, was estimated by the State Board of Health to be 100,000 at that time. The population equivalent for the various municipalities below and including Minneapolis was found in 1927–28 to be as follows: Minneapolis, 550,000; St. Paul, 430,000; South St. Paul and Newport, 415,000 during the months of December and January (estimated yearly average 325,000); Hastings, 900; State Asylum, Hastings, 1300; Red Wing, 10,000; Lake City, 950; Wabasha, 800; Winona, 34,200; and LaCrosse, 26,900.



Courtesy Division of Sanitation, Minnesota State Board of Health

FIG. 1.

In addition to these direct sources of pollution, sewage and wastes are discharged into the Mississippi River indirectly by its tributaries. The population equivalent of the sewage and wastes discharged into the various tributaries is estimated as follows: Minnesota River, 100,000; Cannon, 22,800; Zumbro, 20,000; and Root, 3300. The sewered population on the St. Croix River in Minnesota is 15,000, with treatment of only a small portion of the sewage. In Wisconsin the following sewered populations contribute to the various tributaries: St. Croix and Chippewa, 44,300; Trempeleau and Buffalo, 4500; and Black, 2100, for the most part in an untreated condition.

A summary of these sources of sewage and wastes indicates that a total of 1,780,000 population equivalent is discharged directly or indirectly

into the Mississippi River before it reaches the Iowa-Minnesota state boundary line. In addition to the domestic sewage and industrial wastes discharged into this stretch of the river, pollution from unsewered runoff is carried into the river along its course, for which no allowance has been made in the above estimates, and which, especially during certain periods of the year, may have an important effect.

Method of Calculation

In view of the very large burden placed upon the river, the recovery effected by the combined forces of oxidation, sedimentation, dilution and re-aeration is interesting. The river, as far as the pollution situation is concerned, has two critical periods, one during the summer and another during the winter, when unfavorable stream flow and oxygen content conditions generally combine to produce unsatisfactory conditions. The months of June, July and August are taken to represent the summer condition, except during two years when the flows during June were exceptionally high and the data for that month were omitted. The winter period is considered to extend from December 15 to February 15, when ice coverage generally prevents re-aeration. During the exceptionally mild winter of 1930-31, however, the river, except where the velocity was very low, as behind dams, was open for the greater portion of the winter.

Calculations of deoxygenation have been made in accordance with methods described in *Bulletin* **173** of the U. S. Public Health service based chiefly on the Phelps formula, which assumes that the rate of deoxygenation is directly proportional to the amount of organic matter present. The Phelps formula for deoxygenation is:

Where $$X_t = L(1 - 10^{-Kt})$$

X_t = oxygen used during t days
L = initial oxygen requirement for the carbonaceous stage
K = the deoxygenation constant, which varies with temperature in the following manner: K at any temperature $(T) = K$ at 20° C. times (1.047^{T-20})

As will later be shown the rates of deoxygenation calculated by this formula agree quite closely with those actually observed for the Mississippi River, especially for cleaner water, and are in all cases higher, except for very short periods of incubation, than the observed results.

For purposes of converting population equivalent into pounds of first-stage demand, a factor of 0.24 pound of oxygen per capita per day has been used.

Division of the River

For purposes of calculations the river is divided into the following sections:

(1) North Minneapolis to the Twin City Lock and Dam, a distance of 11 miles in which the average velocity is very low because of the pool created by the dam at the lower end (Stations 1 to 4, Figure 1);

(2) Twin City Lock and Dam to Hastings, where another dam, completed in 1930, creates a pool about 30 miles in length extending upstream to the Twin City Lock and Dam (Stations 4 to 9);

(3) Hastings to Red Wing, a distance of 19 miles, in which the current is relatively swift (Stations 9 to 13); and

(4) Red Wing to Read's Landing, a distance of 22 miles through Lake Pepin, in which the current is ordinarily so sluggish as to be imperceptible (Stations 13 to 15).

(1) **North Minneapolis to Twin City Lock and Dam.**—The river enters Minneapolis in a relatively clean condition. Table I lists the discharge, oxygen content and 5-day biochemical oxygen demand (5-day B. O. D.) of the river at Camden as it enters Minneapolis, averaged for the various periods.

TABLE I

DISCHARGE AND ANALYSIS AT CAMDEN—STATION 1

Period	Discharge, C. f. s.	Dissolved Oxygen, P. p. m.	5-Day B. O. D., P. p. m.
Summer periods			
1926	2400	6.92	1.20
1927	4680	6.74	0.98
1928	5450	6.75	1.68
1929	4130	7.15	1.60
1930	3580	7.66	3.08
Winter periods			
1926–27	2560	6.82	1.15
1929–30	1680	7.20	1.39
1930–31	1745	11.30	1.54

The oxygen content of the water is reduced in this stretch of the river by oxidation of: (*a*) the organic matter already contained in the river water as it enters Minneapolis; (*b*) the pollution contributed by Minneapolis and St. Paul above the Twin City Lock and Dam, located at Station 4; and (*c*) sludge deposits in the pool behind the dam. The effect of the first two sources of oxidation can be evaluated with reasonable accuracy and the third can be determined by subtraction from known quantities. The oxygen content is increased by atmospheric and photosynthetic re-aeration. The rate of aeration used is based upon observations on other watercourses and computations on the Mississippi River for conditions in water flowing at low velocity.

The magnitude of the oxygen requirements of sludge deposits, determined by subtraction as already mentioned, was as follows:

Summer of	Lb. Oxygen per 24 Hr.	Temp., °C.
1926	59,500	22.2
1927	46,800	21.6
1928	57,600	21.6
1929	66,000	23.5
1930	25,200	24.5

Temperatures were recorded at the Twin City Lock and Dam. The explanation for the relatively low result during 1930, contrary to the very uniform results theretofore, is uncertain. The combined effect of two events may account for this low value. In August, 1929, a gate at the lock

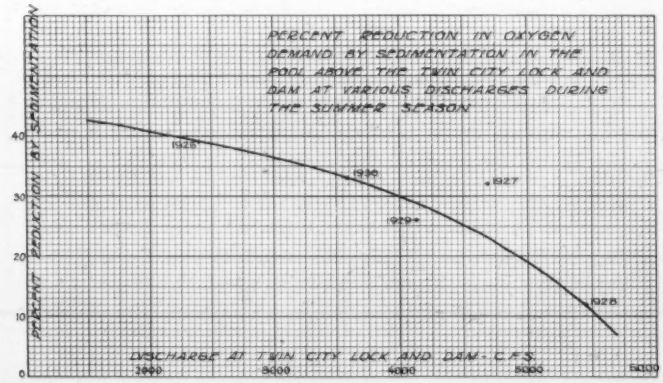


FIG. 2.

at the Twin City Lock and Dam failed, necessitating the lowering of the water in the pool and possibly causing the scouring out of some of the material at the bottom of the pool. The other explanation, and the one which might possibly be given more weight, is that during the summer of 1930 there were more sunny days than normal and as a result there was a superabundance of algae growth as indicated by the comparatively high oxygen content and oxygen demand results for the river water entering Minneapolis. These phenomena were observed elsewhere in Minnesota during this period. The increase in oxygen content caused by algae in the pool above the dam would give a proportionately high dissolved oxygen content at the dam, which would indicate, when calculated as above described, a lower rate of oxidation of sludge deposits than actually occurred. Stated

in another way, the difference between calculated amount of oxygen required by sludge deposits in 1930 and the amounts required in previous years, upward of 30,000 pounds, may represent the oxygen supplied by algae growth during this year over and above that furnished in previous years.

The relation and magnitude of the various factors involved can best be illustrated by the results of the calculations during the summer of 1929, when the following conditions were found:

(*a*) Oxidation of organic material in the river entering Minneapolis, 15,400 pounds;

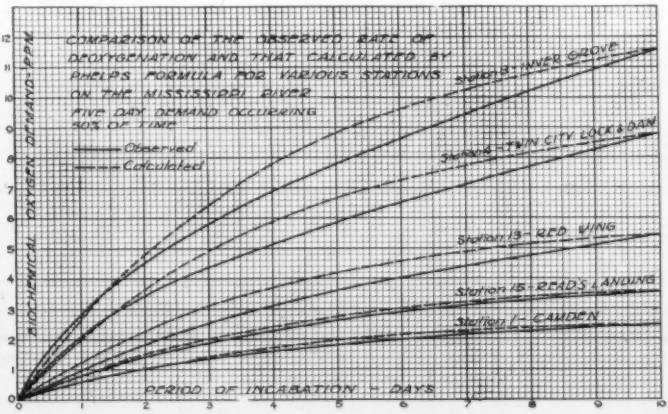

COMPARISON OF THE OBSERVED RATE OF DEOXYGENATION AND THAT CALCULATED BY PHELPS FORMULA FOR VARIOUS STATIONS ON THE MISSISSIPPI RIVER
FIVE DAY DEMAND OCCURRING 90% OF TIME
Observed
Calculated
BIOCHEMICAL OXYGEN DEMAND-PPM
PERIOD OF INCUBATION - DAYS
Station 8 - RIVER GROVE
Station 8 - TWIN CITY LOCK & DAM
Station 13 - RED WING
Station 15 - READ'S LANDING
Station 17 - CAMDEN

FIG. 3.

(*b*) Pollution contributed by Minneapolis and St. Paul above the dam, amounting to 695,000 population equivalent, 25,600 pounds; and

(*c*) Sludge deposits in the pool above the dam, 66,000 pounds.

Re-aeration added 5100 pounds of oxygen in this stretch of the river. The results during the summers of 1929 and 1930 are shown in Figures 5 and 6, and during the winters of 1929–30 and 1930–31, in Figures 7 and 8.

The effect of sedimentation on oxygen demand reduction in the pool above the dam is determined by subtracting the sum of the demand of the water passing the dam and that satisfied by oxidation in the pool, from the sum of the demands of the various sources of pollution. The reduction in oxygen demand during the summer months varied from 12 to 39 per cent, being influenced greatly by river discharge as shown by Figure 2.

In this connection it is both interesting and somewhat surprising to note that under the temperature conditions of the winter periods the effect of sludge deposits and sedimentation in the pool above the Twin City Lock and Dam was apparently negligible. Only during the winter of 1930–31, when the river discharge was very low, was there any indication that sedimentation occurred, and then only to the extent of an 8 per cent reduction in oxygen demand. The fact that the effect of sedimentation was apparently negligible or non-existent during the winter months may be partly ascribed to the increased specific gravity and viscosity of the water at the low temperatures. It is known that low temperatures exert con-

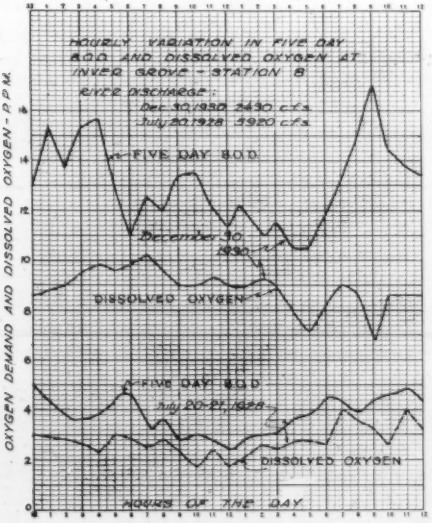

HOURLY VARIATION IN FIVE DAY B.O.D. AND DISSOLVED OXYGEN AT INVER GROVE - STATION B
RIVER DISCHARGE:
Dec 30/1930 2430 C.F.S.
July 20/1928 4920 C.F.S.
FIVE DAY B.O.D.
December 30, 1930
DISSOLVED OXYGEN
FIVE DAY B.O.D.
July 20-21, 1928
DISSOLVED OXYGEN
HOURS OF THE DAY
OXYGEN DEMAND AND DISSOLVED OXYGEN - P.P.M.

FIG. 4.

siderable influence upon sedimentation. According to the relation generally applied, *i. e.*, that the reduction at various temperatures is proportional to the ratio of $\frac{40}{50-t}$ at the different temperatures, the reduction at 0° C. would be only half as much as at 25° C. This, however, does not entirely explain the wide variation between summer and winter results observed.

The conditions of the river water at the Twin City Lock and Dam are shown in Table II.

TABLE II

DISCHARGE AND ANALYSIS AT THE TWIN CITY LOCK AND DAM—STATION 4

Period	Discharge, C. f. s.	Dissolved Oxygen, P. p. m. Observed	Dissolved Oxygen, P. p. m. Calculated	5-Day B. O. D., P. p. m. Observed	5-Day B. O. D., P. p. m. Calculated
Summer					
1926	2400	0.61	0.61	4.45	4.37
1927	4680	3.96	3.96	3.24	3.27
1928	5450	3.69	3.69	3.21	3.18
1929	4130	2.50	2.50	4.26	4.21
1930	3580	3.58	3.58	5.24	5.28
Winter					
1926–27	2560	6.79	7.12*	8.72	7.92*
1929–30	1680	6.50	6.18*	11.60	11.61*
1930–31	1745	9.88	9.60*	10.90	10.90

* The calculated results take into account oxidation of sludge deposits and sedimentation of organic material except for the starred values when the effect of either or both was apparently negligible.

(2) **Twin City Lock and Dam to Hastings.**—After passing the Twin City Lock and Dam, the Mississippi is joined, after two miles, by the Minnesota River, the restorative effect of which, especially under low water conditions, is comparatively small. This is due chiefly to its generally low discharge, frequency curves indicating the existence of flows under 1000 c. f. s. for 30 per cent of the time during the summer months. The discharge from the Minnesota during the summer of 1926 was 350 c. f. s. and in 1930, 835 c. f. s. The degree of pollution of the Minnesota is relatively high.

A small amount of sewage from Minneapolis, 75 per cent of that from St. Paul and all of the sewage from South St. Paul and Newport is discharged into this reach of the Mississippi. Before the construction of the Hastings Dam the velocity in the 30-mile stretch (at 4000 c. f. s.) was comparatively rapid, the flow time from the Twin City Lock and Dam to the site of the present Hastings Dam being then about 1.5 days, whereas with the dam in full operation it will be approximately 9 days. This will have a marked effect on the oxygen balance in the river, as indicated by the results in 1930. During the summer of that year the water at the dam was raised about 7 feet of the total available height of about 18 feet, with the result that the amount of oxidation was materially increased, with a consequent decrease in the oxygen content at the dam. This decrease in oxygen due to increased oxidation was more than counterbalanced by the effect of aeration through the dam which is so constructed as to facilitate aeration.

The flows, observed and calculated analytical data for the river at Hastings, for the years of record are given in Table III.

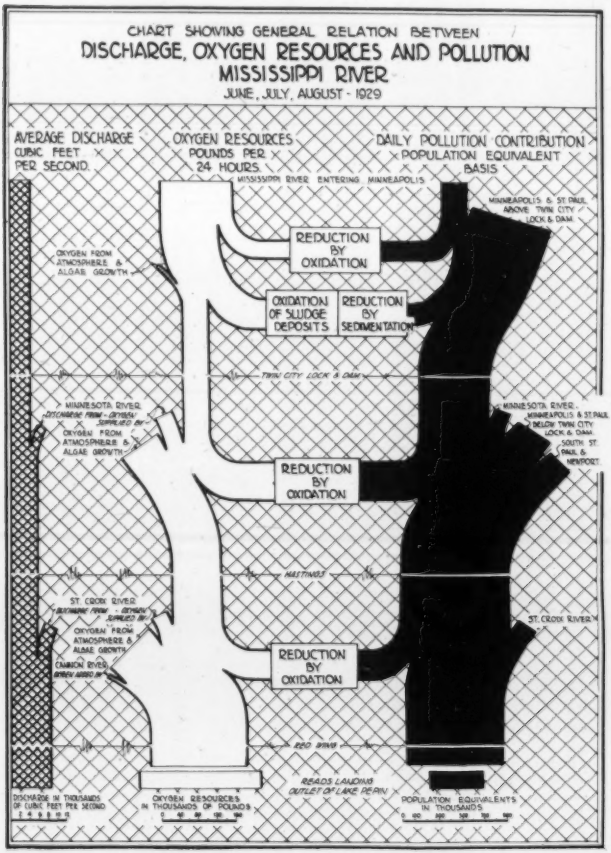


CHART SHOWING GENERAL RELATION BETWEEN
DISCHARGE, OXYGEN RESOURCES AND POLLUTION
MISSISSIPPI RIVER
JUNE, JULY, AUGUST - 1929
AVERAGE DISCHARGE CUBIC FEET PER SECOND
OXYGEN RESOURCES POUNDS PER 24 HOURS
DAILY POLLUTION CONTRIBUTION POPULATION EQUIVALENT BASIS
MISSISSIPPI RIVER ENTERING MINNEAPOLIS
MINNEAPOLIS & ST. PAUL ABOVE TWIN CITY LOCK & DAM
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
REDUCTION BY OXIDATION
OXIDATION OF SLUDGE DEPOSITS
REDUCTION BY SEDIMENTATION
TWIN CITY LOCK & DAM
MINNESOTA RIVER
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
MINNESOTA RIVER
MINNEAPOLIS & ST. PAUL BELOW TWIN CITY LOCK & DAM
SOUTH ST. PAUL & NEWPORT
REDUCTION BY OXIDATION
HASTINGS
ST. CROIX RIVER
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
CANNON RIVER
ST. CROIX RIVER
REDUCTION BY OXIDATION
RED WING
READS LANDING OUTLET OF LAKE PEPIN
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
OXYGEN RESOURCES IN THOUSANDS OF POUNDS
POPULATION EQUIVALENTS IN THOUSANDS

FIG. 5.

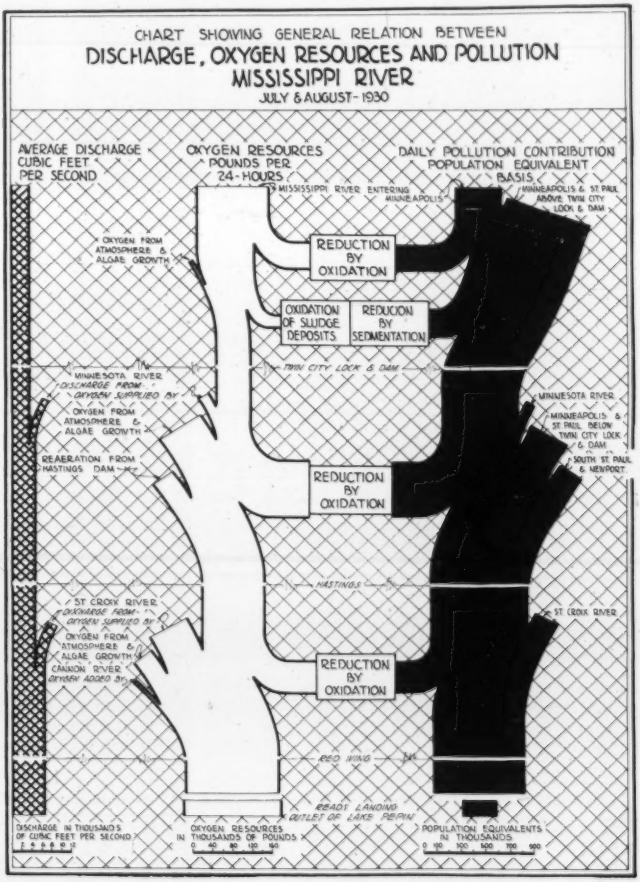


CHART SHOWING GENERAL RELATION BETWEEN
DISCHARGE, OXYGEN RESOURCES AND POLLUTION
MISSISSIPPI RIVER
JULY & AUGUST - 1930
AVERAGE DISCHARGE CUBIC FEET PER SECOND
OXYGEN RESOURCES POUNDS PER 24-HOURS
DAILY POLLUTION CONTRIBUTION POPULATION EQUIVALENT BASIS
MISSISSIPPI RIVER ENTERING MINNEAPOLIS
MINNEAPOLIS & ST PAUL ABOVE TWIN CITY LOCK & DAM
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
REDUCTION BY OXIDATION
OXIDATION OF SLUDGE DEPOSITS
REDUCION BY SEDIMENTATION
MINNESOTA RIVER
DISCHARGE FROM OXYGEN SUPPLIED BY
TWIN CITY LOCK & DAM
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
MINNESOTA RIVER
MINNEAPOLIS & ST PAUL BELOW TWIN CITY LOCK & DAM
SOUTH ST PAUL & NEWPORT
REAERATION FROM HASTINGS DAM
REDUCTION BY OXIDATION
HASTINGS
ST CROIX RIVER
DISCHARGE FROM OXYGEN SUPPLIED BY
ST CROIX RIVER
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
CANNON RIVER
OXYGEN ADDED BY
REDUCTION BY OXIDATION
RED WING
READS LANDING OUTLET OF LAKE PEPIN
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
0 2 4 6 8 10
OXYGEN RESOURCES IN THOUSANDS OF POUNDS
0 40 80 120 160
POPULATION EQUIVALENTS IN THOUSANDS
0 100 300 500 700 900

FIG. 6.

TABLE III

DISCHARGE AND ANALYSIS OF RIVER AT HASTINGS—STATION 9

Period	Discharge at Robert St., St. Paul, C. f. s.	Dissolved Oxygen P. p. m.	Five Day B. O. D., P. p. m. Observed	Calculated	Deviation from Observed	% of Calculated
Summer						
1926	2750	0.27	6.30	7.10	0.80	11.3
1927	6270	3.65	3.06	4.50	1.44	32.0
1928	6550	3.37	4.10	4.51	0.41	9.1
1929	5520	3.55	4.72	5.09	0.37	7.3
1930	4415	3.17*	5.50	5.37	−0.13	−2.4
					Average	12.4
Winter						
1926–27	3000	4.00	7.91	12.50	4.59	36.7
1929–30	1905	4.09	14.60	19.10	4.50	23.6
1930–31	2200	5.98**	10.40	13.85	3.45	24.9
					Average	28.4

* Above dam, 3.17 p. p. m.; below dam, 5.26 p. p. m.
** Above dam, 5.98 p. p. m.; below dam, 8.33 p. p. m.

It will be noted that the difference between the calculated and the observed 5-day B. O. D. averages about 12 per cent during the summer months and 28 per cent during the winter months. The explanation of this difference is interesting. It will be observed that except for the summer of 1930, the calculated results are always higher than the observed. The possible explanation that the effect of sedimentation, which was considered as being small in this relatively fast water, would account for the difference, is partly discredited by the fact that during the summer of 1930 with the Hastings Dam in partial operation, causing a marked reduction in velocity through a portion of this stretch, the calculated result was even lower than the observed. Furthermore, an investigation of the bottom material above and below South St. Paul during the summer of 1930, with the Hastings Dam in partial operation, disclosed the fact that at that time only 1 per cent of the surface material was of an organic nature, compared with 19 per cent in the pool of the Twin City Lock and Dam at the same time. It is possible, however, that sedimentation may exert some influence on the packing plant wastes, which contain a relatively large proportion of readily settleable solids. This effect would be greatest during the winter months when the pollution contributed by the packing plants is about double that contributed during the summer months.

Another attempted explanation was that the rate of deoxygenation was appreciably greater than that calculated according to the Phelps formula: $(X_t = L\ (1-10^{-Kt})$.

A study of the analytical results, which comprised 1-, 5- and 10-day demand determinations for a period of almost 5 years, involving at some stations a total of over 500 analyses, indicated the actual rate of deoxygenation of Mississippi River water to be even lower than that determined by the Phelps formula. At short periods of incubation, however, the rate of satisfaction was slightly higher than that calculated, as shown on Figure 3 for 5-day demands which occurred 50 per cent of the time. This explanation is therefore without foundation.

The real explanation is believed to lie in the effect of hourly variations in the demand of the river water due to hourly variations in sewage flow, coupled with fluctuations in river discharge due to regulation of the Twin City Lock and Dam for power purposes. This accounts for the lower calculated result during the summer of 1930 when partial operation of the Hastings Dam tended to equalize the fluctuation. This effect is more marked at low than at high flows. To determine the variation in river water characteristics, 24-hour samples were collected, composed of 4 samples every hour, under summer and winter conditions and with high and low discharges of the river. The variations are shown in Figure 4, illustrating the fact that the variation between the high and low results was as much as 60 per cent during the summer and 90 per cent during the winter. The Hastings samples are believed to have been collected at such a time of the day as to represent the minimum pollution contributed from the area, thereby giving low values of oxygen demand. When the results are to be used for such a purpose, the advisability of securing a large number of samples at different times during the day, especially at stations near relatively large additions of pollution, is clearly demonstrated.

(3) **Hastings to Red Wing.**—About 2 miles below Hastings the Mississippi is joined by the St. Croix River. This river has a relatively high discharge, a low oxygen demand and a high dissolved oxygen content. Under normal conditions it exerts a marked beneficial effect upon the Mississippi. After its junction with the St. Croix, the Mississippi flows with a comparatively high velocity in a restricted channel a distance of 19 miles to the city of Red Wing. There are no municipalities at the present time that discharge sewage directly into this stretch of the river.

In this section the processes of natural purification, aided as they are by the dilution from the St. Croix, are sufficient to improve the condition of the river to such an extent that this zone can be classified as one of partial recovery.

At Red Wing the river had the characteristics shown in Table IV.

It will be noted that except during the summers of 1929 and 1930 the calculated results, as in the section immediately upstream, are noticeably higher than the observed results.

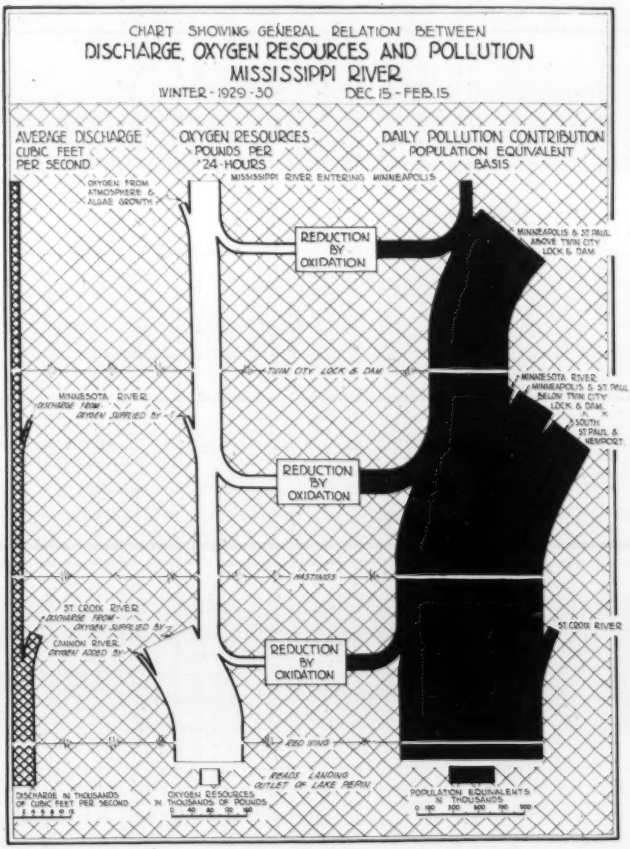


CHART SHOWING GENERAL RELATION BETWEEN
DISCHARGE, OXYGEN RESOURCES AND POLLUTION
MISSISSIPPI RIVER
WINTER - 1929 - 30 DEC. 15 - FEB. 15
AVERAGE DISCHARGE CUBIC FEET PER SECOND
OXYGEN RESOURCES POUNDS PER 24 HOURS
DAILY POLLUTION CONTRIBUTION POPULATION EQUIVALENT BASIS
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
MISSISSIPPI RIVER ENTERING MINNEAPOLIS
REDUCTION BY OXIDATION
MINNEAPOLIS & ST. PAUL ABOVE TWIN CITY LOCK & DAM
TWIN CITY LOCK & DAM
MINNESOTA RIVER DISCHARGE FROM OXYGEN SUPPLIED BY
MINNESOTA RIVER
MINNEAPOLIS & ST. PAUL BELOW TWIN CITY LOCK & DAM
SOUTH ST. PAUL & NEWPORT
REDUCTION BY OXIDATION
HASTINGS
ST. CROIX RIVER DISCHARGE FROM OXYGEN SUPPLIED BY
CANNON RIVER OXYGEN ADDED BY
ST. CROIX RIVER
REDUCTION BY OXIDATION
RED WING
READS LANDING OUTLET OF LAKE PEPIN
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
0 5 10 15
OXYGEN RESOURCES IN THOUSANDS OF POUNDS
0 40 80 120 160
POPULATION EQUIVALENTS IN THOUSANDS
0 100 300 500 700 900

FIG. 7.

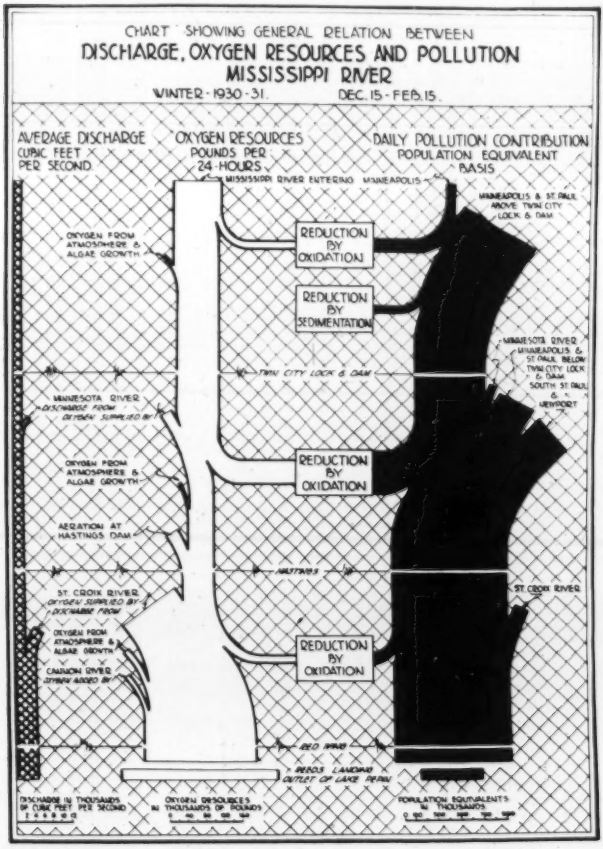


CHART SHOWING GENERAL RELATION BETWEEN
DISCHARGE, OXYGEN RESOURCES AND POLLUTION
MISSISSIPPI RIVER
WINTER - 1930 - 31.
DEC. 15 - FEB. 15.
AVERAGE DISCHARGE CUBIC FEET PER SECOND
OXYGEN RESOURCES POUNDS PER 24 HOURS
DAILY POLLUTION CONTRIBUTION POPULATION EQUIVALENT BASIS
MISSISSIPPI RIVER ENTERING MINNEAPOLIS
MINNEAPOLIS & ST. PAUL ABOVE TWIN CITY LOCK & DAM
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
REDUCTION BY OXIDATION
REDUCTION BY SEDIMENTATION
MINNESOTA RIVER MINNEAPOLIS & ST. PAUL BELOW TWIN CITY LOCK & DAM SOUTH ST. PAUL & NEWPORT
TWIN CITY LOCK & DAM
MINNESOTA RIVER DISCHARGE FROM OXYGEN SUPPLIED BY
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
REDUCTION BY OXIDATION
AERATION AT HASTINGS DAM
HASTINGS
ST. CROIX RIVER OXYGEN SUPPLIED BY DISCHARGE FROM
ST. CROIX RIVER
OXYGEN FROM ATMOSPHERE & ALGAE GROWTH
CANNON RIVER OXYGEN ADDED BY
REDUCTION BY OXIDATION
RED WING
REEDS LANDING OUTLET OF LAKE PEPIN
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
OXYGEN RESOURCES IN THOUSANDS OF POUNDS
POPULATION EQUIVALENTS IN THOUSANDS

FIG. 8.

TABLE IV

DISCHARGE AND ANALYSIS AT RED WING—STATION 13

Period	Discharge, C. f. s.	Dissolved Oxygen, P. p. m.	5 Day B. O. D., P. p. m. Observed	Calculated	Deviation from Observed	% of Calculated
Summer						
1926	5,070	2.19	2.30	3.41	1.11	32.6
1927	10,600	6.08	2.35	2.63	0.28	10.6
1928	11,300	4.13	2.20	2.60	0.40	16.7
1929	8,500	4.43	2.98	2.95	−0.03	− 1.0
1930	6,500	5.42	4.55	3.42	−1.13	−33.0
					Average	18.8
Winter						
1926–27	5,640	7.43	2.99	6.65	3.66	55.0
1929–30	3,985	6.42	4.62	8.75	4.13	47.2
1930–31	4,550	10.00	5.22	6.82	1.60	23.4
					Average	41.8

(4) **Red Wing to Read's Landing.**—Below Red Wing the Mississippi River widens to form Lake Pepin, which is 22 miles in length, has an average width of about 2 miles and an average depth of from 25 to 35 feet. During the summer months the river is greatly improved through this lake, but during the winter, with ice coverage, re-aeration is prevented and the oxygen content drops sharply. The 5-day B. O. D. and dissolved oxygen at Read's Landing are shown in Table V.

TABLE V

ANALYSES AT READ'S LANDING—STATION 15

Period	Dissolved Oxygen, P. p. m.	5-Day B. O. D., P. p. m.
Summer		
1926	5.60	0.93
1927	...	...
1928	6.99	2.06
1929	5.76	1.64
1930	5.62	2.22
Winter		
1926–27	1.77	1.65
1929–30	1.80	2.70
1930–31	13.65	3.65

Re-Aeration

The amount of oxygen absorbed by atmospheric and photosynthetic re-aeration and the rate at which such re-aeration proceeds in various stretches of the river, are important factors in river calculations. Two sections of the river are considered for the purpose of determining the magnitude of these factors, *i. e.*, from the Twin City Lock and Dam to

Hastings and from Hastings to Red Wing. Table VI contains data on re-aeration in these stretches of the river. It will be observed that except for the year 1927 the rate of re-aeration is higher at low oxygen concentrations than at higher ones, as would be expected. The results during 1928, 1929 and 1930 agree quite closely, whereas those during 1926 and 1927 are widely variant, and except for one result are all low compared with later years. Samples during the later years have been collected at the various stations at approximately the same time of day, and hence the effect of hourly variations in oxygen content due to photosynthetic re-aeration, which proceeds very rapidly during the hours of sunlight, has been largely eliminated. Observations at other places indicate that the oxygen content at different times of the day may vary as much as 150 to 200 per cent because of the effect of this phenomenon. Samples during the first two years were collected at the lower stations very early in the morning (five or six o'clock) when the oxygen content would be lower than the daily average, and apparently such data give values for re-aeration considerably below the actual average daily results. The variation in the results indicates the necessity of a greater number of samples collected at different hours of the day so as to make possible determinations of the average oxygen content and the effect of both atmospheric and photosynthetic re-aeration.

TABLE VI

ATMOSPHERIC AND PHOTOSYNTHETIC RE-AERATION IN TWO STRETCHES OF THE MISSISSIPPI—SUMMER MONTHS

	Twin City Lock and Dam to Hastings				Hastings to Red Wing			
Year	Total Pounds per Day	Pounds per 1000 Sq. Ft. of Surface Area per Day	Average Per Cent Saturation of Dissolved Oxygen	Discharge, C. f. s.	Total Pounds per Day	Pounds per 1000 Sq. Ft. of Surface Area per Day	Average Per Cent of Saturation of Dissolved Oxygen	Discharge, C. f. s.
1926	49,000	0.25	8	2,750	2,200	0.02	34	5,070
1927	24,300	0.17	43	6,270	75,400	0.75	56	10,600
1928	62,900	0.48	41	6,550	28,300	0.29	52	11,300
1929	95,600	0.60	42	5,520	37,300	0.36	57	8,500
1930	102,500*	0.47*	40	4,415	45,300	0.41	70	6,500

* Somewhat more quiescent water because of partial operation of Hastings Dam.

Comparison of Summer and Winter Conditions

A study of the tables and charts for summer conditions indicates that in summer favorable temperatures increase the rate of oxidation and result in a comparatively large reduction in the oxygen demand or in population equivalent load carried by the water as it flows downstream. Re-aeration under these conditions plays an important part in restoring the oxygen resources of the river.

In winter, however, low temperatures retard the rate of oxidation, ice

coverage shuts off re-aeration and the river enters Lake Pepin without any very large reduction in pollutional content. The oxidation of polluting material taking place in Lake Pepin greatly reduces the oxygen content, the result of which is to seriously endanger fish life.

Bacterial Content of River

Along with the other determinations, investigations of the bacterial content of the river from North Minneapolis to Wabasha below Lake Pepin were made. These included determination of the total count on agar after incubation for 48 hours at 37° C. and the estimation of the density of organisms of the coli-aerogenes group. In Table VII are shown the coli-aerogenes results for both the summer and winter periods for the years of record. It will be observed that the river water as it enters Minneapolis has a sufficiently low coli-aerogenes mean density to be a suitable source of water supply, when purified and chlorinated in the usual type of water purification works. A *B. coli* density of 5000 per 100 cc. is commonly taken as the upper limit of permissible pollution of a raw water to be subjected to sedimentation, filtration and chlorination. All bacterial investigations were conducted in the laboratories of the Division of Sanitation, Minnesota Department of Health.

Limitations of the Calculations

A comparison between the observed and the calculated values of oxygen content and oxygen demand at various stations on the river demonstrates that the results agree quite closely, considering the number of variables involved. During the five years for which summer records are available the average variation between the calculated and the observed 5-day oxygen demand at Hastings amounts to 12 per cent of the calculated results. The results during the winter months are somewhat more variable. Nevertheless, there is a fairly close agreement between the observed and the calculated results, considering the number of assumptions which had to be made because of incomplete information or uncertainty as to phenomena. The major assumptions and limitations of the calculations are the following:

1. Because of the lack of analytical data on the Minnesota, St. Croix and Cannon Rivers during the years 1929 and 1930 assumptions had to be made to cover this deficiency based on data previously obtained, which showed quite wide variations.

2. The calculated results are based on average seasonal conditions. Hourly and daily fluctuations in river discharge because of regulation for power purposes, variations in sewage flow, and in rate of re-aeration as influenced by sunlight necessarily cause individual samples to differ from the average. The observed results indicate the condition of the river only at the time of sampling, which may vary considerably from the weekly or even the daily average.

TABLE VII

MISSISSIPPI RIVER, CAMDEN TO READ'S LANDING—ORGANISMS OF THE COLI-AEROGENES GROUP

Per Cubic Centimeter

Sampling Point	Summer Periods—June, July and August					Winter Periods—December, January and February		
	1926	1927*	1928	1929	1930*	1926-27	1929-30	1930-31
Camden	2.3	5.5	6.1	4.6	0.6	12	10	19.2
Washington Ave.	....	....	2010	700	229	....	2820	1550
Twin City Lock and Dam	1735	2247	3170	1650	490	1162	3900	1740
Minnesota River	4.3	21	7.4	....	....	7.7	....	140**
Robert St.	2198	834	....	2310	....	884	4530	....
St. Paul Terminal Ry.	....	....	870	820	1790	....	3900	1740
Inver Grove	947	662	2160	3450	1000	1671	3720	3810
Hastings	6598*	258	550	3550	357 Above 344 Below	488	1920	1640 Above 720 Below
St. Croix River	202*	0.3	2	....	....	4.8	....	0.3**
Cannon River	13*	3.5	21	....	....	5	....	....
Red Wing	145*	17	486	40	37	31	203	205
Read's Landing	2*	....	0.5	0.4	0.4	0.3	0.4	.1

* July and August only.

** January and February only.

3. The rate of deoxygenation used has been that calculated according to the Phelps formula. Comparison of this formula and the rate actually observed for the river water and for packing plant wastes indicate that especially for freshly polluted water there may be quite a variation between the two rates when computed over long stretches of the river.

4. The determination of the actual time of flow in the river is an important factor, which is somewhat uncertain when dams and wing dams are constructed in long stretches of the river channel.

General Observations

The analytical data on the Mississippi River and the interpretations and calculations presented herein form the basis of some very interesting observations of general interest, as follows:

1. The effect of sedimentation in pools created by dams may in certain instances be a very important factor in river calculations. In the case of the Twin City Lock and Dam sedimentation apparently accounts for reduction in oxygen demand varying from 10 to 40 per cent during the summer months, dependent largely on river discharge. Under the temperature condition of the winter months the effect of sedimentation is either very low or negligible, a phenomenon which is somewhat surprising in that it cannot entirely be explained by temperature variations calculated in the usual way.

2. The amount of oxygen required for the oxidation of sludge deposits in the pool of the Twin City Lock and Dam averages about 50,000 pounds per day during the summer months, or 1.35 pounds per 1000 square feet of pool area per day. At an average discharge of about 4000 c. f. s. this amounts to 2. 3 p. p. m. of dissolved oxygen, which except for one summer period is almost twice that required for the oxidation of the material in solution or suspension. During the winter months oxidation of sludge deposits apparently has but a slight effect upon the oxygen balance.

3. During the summer season atmospheric and photosynthetic re-aeration adds appreciably to the oxygen resources of the river. Based on the results of later years, approximately 0.50 pounds of oxygen are supplied per 1000 square feet of surface area per day in the stretch from the Twin City Lock and Dam to Hastings at a dissolved oxygen saturation of 40 per cent, and 0.35 pounds per 1000 square feet per day from Hastings to Red Wing at a saturation of 60 per cent.

4. Hourly variations in sewage and river discharge have an important effect on the precision with which calculations and comparisons can be made, especially in fast water at sampling stations immediately below relatively large sources of pollution. In such cases a large number of samples collected at different times of the day is necessary in order to determine with accuracy the average quantity of pollution carried by a river, and the effect of various deoxygenation and re-aeration factors.

The Effects of Sewage Discharge on Streams*

BY H. W. STREETER**

The subject of this paper probably would have been of little or no interest to our pioneer forefathers, whose methods of wastes disposal were simpler than those of the present day and were attended by less far-reaching consequences to their more remote neighbors although their immediate effects, both atmospheric and otherwise, may have been more obnoxious.

Our present civilization has been attended by many blessings but also by their accompanying penalties. One of the undoubted blessings is the modern water-carriage system of sewage disposal, which has brought with it not only a greatly enhanced standard of household and public decency, but also a definite saving of human lives. Among the penalties, however, we must include sewage and its attendant evil, stream pollution, which have imposed on communities, states and even federal governments a problem so highly ramified, in its technical and legal aspects, that it well may challenge the combined resources of these agencies. In this paper it is proposed to consider very briefly some of the effects, both immediate and more remote, which are caused by the discharge of sewage into streams, having particular reference to those effects which bear on the more common uses made of streams in this country.

The extent of stream pollution in the United States due to untreated sewage and industrial wastes is well illustrated by conditions in the great Ohio River basin, in which it may be roughly estimated that the sewage of about 6,000,000 people is discharged without treatment into this river and its tributaries. It has been estimated recently in *U. S. Public Health Bulletin* **193,** page 7, that the wastes of over 6,000,000 people, or their equivalent, are discharged, directly or indirectly, into the Great Lakes along their American shores and interconnecting waters. That sewage treatment has not been, thus far, a very important factor in the situation is indicated by the estimate made in 1915 in *U. S. Public Health Bulletin* **143,** page 77, that in the Ohio River basin only 12 per cent of the total sewered population was served at that time by sewage treatment in any degree and only 2 per cent of the total, representing less than 100,000 people, by reasonably complete sewage treatment. It is doubtful if the percentages would show a very substantial increase at the present time.

From a utilitarian point of view, the effects of stream pollution by sewage may be summed up under the following headings:

1. Damage to water supplies, both public and industrial.

* *Presented before the Fifth Annual Meeting of the Pennsylvania Sewage Works Association, State College, June 23, 1931.*

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2. Injury to property values, through the setting up of nuisances and other conditions offensive to riparian dwellers.

3. Destruction of fish and other natural aquatic life, through suffocation and introduction of toxic substances into streams.

4. Damage to streams for recreational uses.

5. Injury or destruction of the powers of streams for natural purification.

6. Damage to agricultural interests, notably through rendering surface waters unfit for use by cattle.

7. Detrimental effects on uses of streams for navigation and power.

In addition, the recent drought period (1930–31) has afforded some presumptive evidence, not as yet proven, that the excessive pollution of streams by sewage, or by certain kinds of industrial wastes thus far not identified, may result, under some conditions, in the contamination of water supplies by substances, possibly chemical in their nature, which are not removed by ordinary processes of water purification and which are sufficiently toxic to cause widespread gastro-intenstinal disturbances in human consumers of the water.

The several effects above enumerated may be attributed to three general conditions in streams, resulting from sewage pollution. These are:

1. Excessive bacterial pollution, notably by organisms of human intestinal origin.

2. Over-depletion of the normal dissolved oxygen content of stream waters.

3. The presence of specific substances in stream waters which may exercise toxic effects on human or domestic animal consumers of the water; may render it unfit for industrial or general domestic use; or may cause damage to bridges, dams and other structures in or along the stream.

Bacterial Pollution.—Normal domestic sewage may contain from 1,000,000 to 10,000,000 countable bacteria per cubic centimeter, of which 100,000 or more may consist of intestinal organisms of the *B. coli* group. On the basis of the average numbers of *B. coli* estimated by various observers, which would approximate 400,000 per cc., the total numbers of this group of organisms normally contributed, as sewage, by human beings would be roughly estimated as about 200 billion per capita daily. Measurements made by the U. S. Public Health Service have indicated that the immediate increase in the *B. coli* content of certain river waters resulting from the discharge of untreated sewage from urban areas such as Cincinnati, Louisville, Chicago and Peoria, corresponds to a contribution ranging from 190 to 360 billion per capita daily and averaging about 250 billion. Although these figures are based on measurements in streams and thus represent the observed effects of combined sewage and surface drainage water, they correspond fairly well to the total numbers of *B. coli* observed nor-

mally in sewage. They are considerably higher, however, than the numbers observed in human feces, which have ranged from 5 to about 10 billion per capita daily. The margin of difference thus shown between the *B. coli* content of feces and of normal sewage suggests that bacteria originating in the intestine may undergo some degree of multiplication or subdivision after being diluted by the water content of sewage.

After the intestinal bacteria of sewage have been diluted by discharge into a stream, they appear to undergo a further increase in their total numbers, reaching a maximum several hours after reaching the stream, the time required to reach the maximum being shorter in summer than in winter. The attainment of this maximum is followed ordinarily by a progressive decline in bacterial numbers, related to time rather than distance, and proceeding at a rate which diminishes with increased time of flow and also varies seasonally with temperature. This bacterial decline is subject, intermittently, to disturbances resulting from inflowing drainage water, which may add either polluting material or diluting water to the main stream. It also usually is subject to the effects of alternating sedimentation and channel scouring, according to whether low-water or high-water conditions prevail in the stream. One or more of these several modifying influences may disturb, in some degree, the normal course of natural purification. Under some conditions, notably when periods of high water occur in the winter or early spring, they may combine in such a manner as to nullify completely the progressive improvement in the quality of the stream water which under other conditions may be clearly observable. These periodic upsets constitute perhaps the weakest link in the natural process of stream self-purification, in so far as its effectiveness as a practical safeguard is concerned.

In this connection, it may be of interest to note here a somewhat surprising fact concerning the effect of dilution water on the bacterial content of streams. Contrary to what might be expected, the addition of dilution water through tributaries less polluted than the main stream has been observed frequently to result in an increase, rather than a decrease, in the bacterial content of the main stream. Although the specific cause, or causes, of this increase have not yet been determined, its occurrence is entirely consistent with that which has been observed, first, in the transition of feces to sewage and, second, in the passage of sewage into a stream. It is possible that each one of these increases may be due to an actual multiplication of sewage bacteria, or merely to the further disintegration and comminution of suspended matter, containing masses of these bacteria. Whatever its cause may be, it appears to be a well-established phenomenon, of which due account should be taken in tracing quantitative changes in the bacterial content of sewage-polluted streams.

In spite of the disturbing influences which have been noted, the forces

of natural purification actually bring about a well-marked improvement in the bacterial quality of many stream waters, even where the regimen of flow is quite variable and the unbalancing effects of inflowing drainage water are relatively great. In the larger rivers the rate of improvement tends to be measurably slower than in small streams, though it is difficult to say, with our present knowledge, whether the difference is real or apparent; that is, whether it is attributable to a definite scale factor, or is merely due to the more intensive biological conditions found in many small streams polluted by sewage. There seems to be fairly reliable evidence indicating that the rate of bacterial self-purification is affected to a well-marked extent by the intensity of pollution of a stream. Thus, in zones of the Ohio and Illinois rivers located immediately below major sources of pollution, the observed rate is measurably greater than in stretches of the same rivers further removed from these sources.

Of the complex forces causing the natural reduction of sewage bacteria in streams, we know comparatively little, except through indirect inferences based on observation and laboratory experiment. In many streams, sedimentation undoubtedly is a powerful factor in depositing many of these bacteria along the sides and bottom of the channel, where they are subject to the destructive influences of their natural enemies, the animal plankton, which prey on them for food. Where conditions in a stream are fairly stabilized, the activities of these bacteria-consuming plankton also probably are an important influence in destroying many of the bacteria adhering to suspended matter. In relatively clear streams, the actinic power of direct sunlight doubtless exerts a marked bactericidal effect, though in turbid streams its influence is more doubtful. In many instances, available food supply probably is an important factor in determining the maximum bacterial population which a stream will support. It is a matter of observation that the minimum bacterial content of a given stream after the forces of natural purification have virtually spent themselves, tends to reach a general level bearing some relation to the concentration of organic food material in that particular stream.

Finally, it may be said that the all-important element in the fate of sewage bacteria in streams and other bodies of water is time, rather than distance. It used to be said, and still is believed by many persons, that a river purifies itself in a stated number of miles. This misconception has been due largely to the fact that the earlier observations of stream purification were made on relatively small streams of fairly uniform regimen, similar to those found in England and in some of our northeastern states. Later observations on the highly variable and larger rivers of the inland sections of this country has shown very conclusively that between two fixed points on a given stream, though located many miles apart, widely varying degrees of bacterial reduction may be observed, depending

on the time of flow existing temporarily between the two points. These observations serve to emphasize both the limitations and the extreme variability of the forces involved in natural stream purification.

Effects on the Oxygen Balance.—In the pre-war days of European diplomacy, we heard much of the "balance of power" among various states. In these present days of more peaceful pursuits, we likewise hear much of the "balance of oxygen" in our streams. Although the analogy between the two terms may not appear, at first sight, very obvious, it nevertheless is a very close one—in fact, a balance of oxygen virtually means a balance of power in determining the ability of sewage-polluted streams to maintain their capacity for natural purification.

Domestic sewage and many industrial wastes contain large amounts of organic matter, of such a nature chemically that it is capable of being oxidized to fairly simple and stable end-products, such as carbon dioxide, carbonates, nitrites and nitrates. In the presence of a supply of available dissolved oxygen and with the aid of oxidizing bacteria, the oxidation of the organic matter will occur, at rates depending, among other things, upon the temperature of the medium and the extent to which the multiplication of oxidizing bacteria is taking place. The oxygen demand of normal sewage has been estimated as being equivalent to roughly $^1/_4$ pound of oxygen per capita per day.

The earlier observations of Dr. Adeney and his co-workers in England and later studies by Theriault in this country have shown that the oxidation of sewage proceeds in two distinct stages, each merging into the other. The primary stage is marked by the oxidation of the carbonaceous matter, and the secondary stage by nitrification, or the oxidation of the nitrogenous material. Under laboratory conditions, Theriault has found that the time required to complete the primary, or carbonaceous, oxidation phase varies from about 6 days at 30° C. to nearly 20 days at 9° C. Approximately equal times appear to be required to complete the secondary, or nitrification, phase.

The biochemical oxygen demand of sewage being far in excess of the very limited amount of oxygen which its water content will hold in solution, this oxygen soon becomes exhausted in order to satisfy the small fraction of the demand represented by the first few hours of oxidation. If more oxygen is not furnished, either by dilution or re-aeration, anaerobic decomposition of the sewage will occur and a series of soluble and readily oxidizable products will be formed, constituting the so-called "immediate" oxygen demand, which differs from the "biochemical" demand in being, or simulating, a true chemical reaction. Recent studies by Theriault have shown that this so-called "immediate" or chemical demand is not actually satisfied instantaneously, when a supply of oxygen is brought into contact with it, but at a rate about 15 or 20 times that of ordinary bio-

chemical oxidation. Thus, at 20° C., about 24 hours is required to satisfy substantially all of this rapid demand.

When sewage is discharged into a stream, the progress of oxidation appears to proceed virtually at the same specific rate as in the laboratory, except as modified by the presence of an "immediate" oxygen demand (if the sewage be in a septic condition) and by the influence of the stream temperature, which in winter may retard the oxidation reaction and in midsummer may accelerate it. The apparent rate of oxidation, as measured by the observed decrease in the biochemical oxygen demand of the stream water from point to point, will be affected, however, by the removal of suspended oxidizable matter through sedimentation and absorption along the sides and bottom of the channel. Available evidence indicates that the organic matter thus removed from the flowing stream is oxidized gradually at the usual biochemical rate, where it lies sufficiently close to the surface of the sludge deposit to utilize the dissolved oxygen content of the overlying stream water. In the lower strata of such a deposit, the material does not appear to be oxidized biochemically to any large extent, though a portion of it probably decomposes anaerobically and forms soluble end-products which impose a chemical oxygen demand on the overlying stream.

The extent of oxygen demand exerted by sludge deposits may be very large, under some conditions, and probably is always a considerable factor in the burden placed on the oxygen resources of a stream in which sedimentation is occurring. From a study of the Illinois River, the Engineering Board of Review of the Sanitary District of Chicago (Feb., 1925) concluded that in this river the oxygen demand imposed by sludge deposits was at that time about 35 per cent of the total demand exerted by the entire volume of sewage discharged into the river. Some recent observations made in an experimental stream channel at the U. S. Public Health Service laboratory at Cincinnati, and reported in *Industrial and Engineering Chemistry*, December, 1930, have indicated that 40 per cent of the total oxygen demand of this stream was exerted by the sludge deposits which had accumulated in the channel over a period of several months. From these and other observations, it appears that sludge deposits may be a very large factor in the burden imposed on the oxygen resources of a stream and that the oxygen demand exerted by these deposits is to a large extent a function of their total surface area, rather than their total volume.

In order that oxidation may proceed in a sewage-polluted stream, a continual new supply of available oxygen must be brought into solution in the stream water, as the total amount of oxygen which the water will hold in solution at any given time may be considerably less than that which is required to satisfy the oxygen demand. In general, this additional oxygen appears to be furnished very largely through atmospheric re-aeration, or direct absorption of oxygen by the stream from the atmosphere,

though under certain conditions the supply from this source is augmented very materially by photosynthetic action of oxygen-producing aquatic plants, notably the green algae.

A concrete idea of the large amounts of oxygen absorbed from the atmosphere by streams may be gained from the results of an estimate by the Engineering Board of Review for the Sanitary District of Chicago (Part III, Appendix 1, Tables 98 and 99) on the volume of oxygen thus absorbed by the Illinois River. It was estimated by the Board that in the upper stretch of this river extending from Joliet to Chillicothe, 107 miles long, approximately 1,000,000 pounds of oxygen per day were absorbed from the atmosphere under summer conditions. The rates of absorption thus observed ranged from 2 to as much as 16 pounds per day per 1000 square feet of water surface.

The rate of absorption of atmospheric oxygen by streams varies widely and is governed very largely by the depth and turbulence of flow, by the amount of surface area in proportion to depth and by the deficiency of the dissolved oxygen content below the saturation value at the prevailing stream temperature. It also appears to depend, to some extent, on the temperature of the stream water. Little definite quantitative information exists as to the rate at which oxygen is supplied through the photosynthesis of aquatic plants, though it is known to vary widely with the intensity of daylight and is practically suspended during the night. It probably also varies with different kinds of plants and presumably is roughly proportionate to the density of these plants in the water at any time. Oxygen photosynthesis probably exerts its greatest influence during the summer and autumn months in quiescent or semiquiescent ponds and river pools, where biological conditions are more stabilized than in the more actively flowing streams.

The rate of progressive change in the dissolved oxygen content of a stream at any time is represented quite obviously by the difference between the rates at which deoxygenation, to satisfy the oxygen demand, and re-aeration, either by photosynthesis or by absorption of oxygen from the atmosphere, are proceeding at that time. In general, the course of change in the dissolved oxygen content of a stream below a major source of pollution tends to follow a fairly definite "sag" curve, which is marked by a progressive decline in the dissolved oxygen content to a minimum point, followed by a gradual recovery toward the oxygen saturation value. Under practical conditions, however, the shape of this curve may be modified very considerably by the effects of sedimentation, stored sludge deposits and inflowing pollution or dilution water.

A number of attempts have been made to estimate, from observations in streams, the extent to which the existing course of the dissolved oxygen "sag" curve might become altered by increased sewage pollution or, con-

versely, by reduction in the degree of such pollution. On the basis of such an estimate, it was predicted by Phelps and the writer several years ago in *U. S. Public Health Bulletin* **146,** page 62, that serious depletion of the dissolved oxygen in Ohio River water might be expected to occur immediately below Cincinnati if a critically low dilution of about 11 parts of river water to 1 part of sewage should at any future time be reached at that point. Although such a low dilution ratio was not expected to occur until such time as Cincinnati had greatly increased in size, it was actually reached during the extreme drought of the summer of 1930, when, as predicted, the dissolved oxygen content of the river below the city became practically depleted. Similar estimates were made by the Chicago Engineering Board of Review of oxygen conditions to be expected in the Illinois River as the result of various assumed modifications in the extent of pollution of the river by Chicago sewage and in the amounts of dilution water diverted from Lake Michigan. Although estimates of this kind are of great practical value, our knowledge of the effects of certain complicating factors, notably that of sludge deposits, is not yet sufficiently advanced to permit the formulation of any general method for solving these problems, applicable to all conditions of practice.

Effects of Toxic and Other Chemical Substances.—Finally, let us consider very briefly the effects which toxic and other chemical substances originating in sewage and industrial wastes may exert on streams into which such wastes are discharged. Aside from a few of the more obvious cases, our knowledge of this phase of the subject is indeed very limited.

As regards toxic chemical substances, we can say with reasonable assurance that normal fresh domestic sewage, containing no industrial wastes, usually does not carry them in any marked degree, though Theriault recently has found measurable amounts of phenol both in ordinary sewage and in river water highly polluted by sewage. Where sewage undergoes septic fermentation, either in its full strength or after being diluted in a stream, a series of highly toxic substances, such as skatol and indol, may be formed. Although no definite evidence exists as to whether they ever become sufficiently concentrated in a receiving body of water to exert a toxic effect on human or animal consumers of the water, such a possibility cannot be wholly discarded, in view of a number of unexplained outbreaks of gastro-intestinal disorders, apparently water-borne, which have occurred during the recent period of drought in certain cities having well-purified water supplies, bacteriologically safe according to current standards, but taken from sources highly polluted by sewage. In cases of this kind, the possibility always exists that toxic substances originating in some forms of industrial wastes may become sufficiently concentrated in streams during periods of extreme drought to cause trouble.

In general, however, the deleterious effects of chemical substances

originating in industrial wastes are manifested in streams most commonly by their interference with the normal processes of self-purification and by the difficulties which they cause in the efficient operation of water purification plants. The first of these two difficulties results largely from the toxic effects which some chemicals, notably acids, may exert on the plankton and higher aquatic life in streams, the maintenance of which is essential to their effective, natural purification. In some cases a temporary improvement in the condition of the stream may result from the destruction of bacteria, but in such instances the burden of natural purification usually is shifted to some downstream zone of the river.

Difficulties in water purification arise most frequently from the intermittent and often sudden appearance of chemical substances in the raw water which interfere with its proper coagulation. Tannins, lignins, acids and certain colloidal substances are especially bad offenders in this respect. Another source of trouble to the filter plant operator during recent years has been the presence of taste-producing substances in raw waters, some of which are not susceptible of removal by ordinary methods. Perhaps the best-known of these substances have been the phenols, the taste-producing properties of which are intensified by chlorination of water containing them. During the drought period of 1930, another class of substances, giving rise to musty tastes in purified waters, was encountered in streams of the Ohio River basin. Considerable success in dealing with these disagreeable tastes in water has been experienced through the use of activated carbon and the substitution of chloramine for chlorine as a disinfectant.

With certain exceptions, such as those above noted, our knowledge both of the causes and of the effects of chemical substances arising from stream pollution is very limited. In dealing with toxic substances, which frequently are somewhat obscure in their chemical nature, the water chemist is handicapped by the lack of specific quantitative chemical tests for such substances, when present in the extremely minute amounts in which they usually occur in streams. This phase of the problem offers a particularly good field for valuable chemical research work.

Conclusions

In concluding this paper, it may be desirable to touch very briefly on the much debated question of permissible limits of stream pollution, which bears a direct relation to the subject under discussion.

In some foreign countries, notably Great Britain, we find considerably greater uniformity both in views and laws on this question, than in the United States, where conditions affecting stream pollution vary more widely than in many other countries.

Up to very recently, standards of stream pollution have been based

almost wholly on requirements for preventing local nuisance. An example of such a standard is that of the British Royal Commission, specifying the maximum allowable oxygen demand of stream waters consistent with their satisfactory degree of purity; likewise the maximum suspended matter content and oxygen demand of sewage effluents. Other examples are the various standards of minimum dilution of sewage by streams, proposed in this country from time to time, notably the dilution standard initially recommended for the Chicago Drainage Canal, which provided for a dilution ratio of 3.3 cu. ft. per second per 1000 of sewered population.

Although dilution standards of this kind are still applied quite widely in this country, a tendency now exists toward endeavoring to base criteria of allowable stream pollution on certain minimum requirements with respect to the quality of the stream water itself, depending on the major use to which a particular stream is devoted. Where preservation of fish life is of primary importance, a minimum dissolved oxygen content of the stream water, usually about 4 p. p. m., is specified. Where prevention of nuisance is of major importance, the minimum allowable dissolved oxygen content may range from 2 to 4 p. p. m., or higher, depending on local conditions. In streams used primarily as sources of water supply, the present tendency is toward standards of bacterial quality of their waters at intakes from which raw water supplies are taken for purification. In view of the widely varying conditions met in this country, the endeavor to fix limits of stream pollution on a basis of essential quality requirements for stream waters, rather than on minimum dilution ratios, seems to be the more logical method of approach.

Because of the very widespread use made of our rivers and lakes as sources of water supply, the question of how highly polluted they may safely be allowed to become has been much discussed of late. It also is becoming a matter of increasing importance in some European countries, where the necessity of utilizing surface sources of water supply to a greater extent in the future than in the past is apparent.

On this question we find rather widely divergent views among sanitarians in this country. At one extreme are those who would eliminate practically all direct sewage pollution of streams used as sources of water supply. At the other, are those whose faith in the efficacy of modern water purification systems apparently would lead them to condone, if not advocate, the virtually unlimited pollution of our water-courses. In the middle ground are those, probably constituting a large majority, who favor prescribing well-defined limits of pollution, based on the margin of safety within which efficient water purification systems can produce effluents of acceptable palatability and bacterial quality. Such limits, as observed under conditions of actual practice, have been determined by the U. S. Public Health Service from an exhaustive study involving detailed obser-

vations of the performance of over 30 municipal water filtration plants, supplemented by operation of a fully equipped experimental filtration plant for a period of five years.

To sewage works engineers and managers, these matters are of vital, if indirect, importance, because upon them must fall the task of providing adequate facilities for relieving excessively polluted streams from overburden. As our rivers become more highly charged with sewage and industrial wastes, their task will become more exacting and will demand increasing foresight. Sewage works managers are now devoting more study to the streams receiving the effluents of their plants, realizing that many of the chemical and biochemical changes in sewage incidental to its artificial treatment must be completed in the receiving watercourse through the agencies of natural purification. From this point of view, sewage treatment is the starting mechanism which sets in motion the machinery of purification. If the starter jams, the entire mechanism is stalled.

If this paper holds any message to the sewage plant manager, it may be summarized very briefly as, "Watch your streams." In a very real sense, they are the final criterion of accomplishment. Screens, tanks and filters are but means to the end, which lies, not in the effluent conduit but in the stream.

Editorial

Mechanical Dewatering of Sludge

A remarkable interest has developed quite recently in the possibility of partially dewatering digested and even freshly settled sludge, with or without activated sludge, by means of vacuum filters. The problem is not so much the determination of whether or not such sludge can be filtered, but rather the determination of the rates of filtration, cost of conditioning chemicals and moisture content of the filtered sludge.

Renewed interest in this direction is due to the desire to find some alternative to the present method of sludge disposal by drying on sand beds. Although sand-bed drying has been modified by the development of mechanical cleaning machines for large-scale operation and by glass-over construction, such drying is still essentially a seasonal proposition, with large areas of sand beds and considerable equipment lying idle throughout the winter. During cold weather, storage space must be provided in Imhoff or separate digestion tanks, and this additional capacity must also be charged to sludge disposal. If mechanical dewatering of digested sludge can be operated continuously, winter and summer, it will not be necessary to provide storage capacity or sand beds. If fresh sludge were handled, digestion tanks could also be eliminated.

Experimental work on dewatering of digested sludge with vacuum filters is now in progress or immediately contemplated at Baltimore, Chicago, Columbus, North Toronto and Los Angeles. Activated sludge has been dewatered on vacuum filters during the past eight years, with installations at Milwaukee, Chicago, Indianapolis, Houston, Charlotte and Pasadena. In very recent work at Chicago, a mixture of freshly settled and activated sludges, concentrated in primary settling tanks, is being filtered. The nature of the mixed sludge and the possibility of concentration to 95 or 96 per cent moisture content, or lower, may make it possible to get considerably higher rates of filtration than have been obtained with activated sludge containing 98.5 or 99 per cent moisture. Furthermore, if fresh sludge can be filtered without difficulty, the logical means of final disposal would seem to be by incineration of the filter cake. Even filter cake from digested sludge might have to be dried mechanically before final disposal. The possibility of eliminating digestion, storage and sand beds by filtration and incineration is being studied by the Sanitary District of Chicago. The conclusions will depend upon the cost of the new methods as compared with the old.

Return to the almost obsolete practice of filtration of fresh or digested sludge might seem to be a rather reactionary procedure were it not for the fact that vacuum filters and ferric-chloride treated sludge offer a far more attractive combination than the old-fashioned plate-and-frame filter presses and lime-treated sludge.

Many comparative combinations should be studied, such as fresh *vs.* digested sludge, incineration *vs.* fertilizer production and mechanical sludge disposal *vs.* digestion and drying on sand beds. The possibilities certainly warrant thorough investigation.

Profitable Sewage Treatment

No process of sewage treatment has yet been developed to operate at a profit. Notwithstanding repeated reference for the past fifty years to the potential values present in sewage as fertilizer, grease or fuel, no process has been perfected to recover such values profitably. In fact, progress in sewage treatment during the past decade has been marked by increasing popularity of the activated-sludge process, which is known to be expensive in operating cost, but which produces such a superior effluent, and such freedom from nuisance, as to justify its additional cost. Many improvements have been discovered whereby the cost of operation of activated-sludge plants can be reduced, and mechanical equipment of all varieties is used to improve the results of treatment or to lessen the costs.

The success of a few companies in the sale of sewage treatment equipment has apparently stimulated the development of other concerns interested in the sale of patent rights or licensing fees for new and untried processes. The increasing mechanization of sewage treatment may provide a legitimate field for the sale and use of good equipment, but when the proposed processes wander off into the twilight zone of bacterial cultures, fertilizer mixtures, electrical phenomena and colloid coagulation, a careful analysis of the proposals is essential.

Many of these so-called "new processes" have been announced within the past few years, most of them having to do with the disposal of sludge For some time it has been possible to obtain a small income from air-dried digested sludge at a few sewage treatment works. This has led to schemes for sale of such sludge as a base for a more or less complete mixed fertilizer, valued at considerably more than is justifiable from its nitrogen, phosphoric acid and potash content. This excessive valuation is ascribed to its "humus" content, or its value as a "soil corrective," familiar terms to many sewage chemists. While well digested and dried sludge undoubtedly is of value as humus for certain soils, such value is not sufficient to pay for its

shipment for any appreciable distance, thus limiting its use to the vicinity of the treatment works. Activated sludge prepared as a fertilizer has enough value to warrant shipment for considerable distances, but its value is determined by its fertilizer constituents, primarily nitrogen. Even the high nitrogen and phosphoric acid content of activated sludge does not give it sufficient value to equal the total cost of preparation. Other types of sewage sludge contain far less nitrogen and phosphoric acid than activated sludge.

The cost of the treatment of sewage must also be added to the cost of sludge disposal, making a total expense considerably greater than any present prospect of income from sale of sludge. The cost of treatment is largely power and labor for activated-sludge treatment and fixed charges on a large initial investment for trickling filters. Chemical precipitation, which does not produce an effluent equal to that from the activated-sludge or trickling-filter process, is sometimes claimed to be nominal in cost of operation. The validity of this claim depends upon the meaning of the word nominal. Webster says it means "existing in name only; not real or actual; merely named, stated or given, without reference to actual conditions." Some estimates of cost conform to this definition.

Although the net expense of all processes of sewage treatment is considerable, so much study is being devoted to means for reducing this expense that appreciable economies are bound to result. A hopeful attitude and an unprejudiced view-point should make it possible to take advantage of true progress without being misled by false claims of inexperienced or unscrupulous promoters.

Beauty and Sewage Treatment Works

Some sewage treatment specialists with esthetic natures may be disturbed by the view-point of Professor George M. Merrill, as expressed by his article in this issue, in which he discusses the landscape treatment of sewage treatment works. Professor Merrill says that "gaudy flowers and ostentatious shrubs or trees are as inappropriate as an attempt to make a lavatory a center of attraction by decorating it or by calling special attention to it." This view-point would seem to differ somewhat from the sentiments expressed not long ago by Mr. Morris M. Cohn, of Schenectady, who said "Humming birds and butterflies will pay a visit to the pollen treasures of your flower beds and picnickers will spread their lunches in the shade of the majestic trees." This lyric could end on a musical note if the last phrase were changed to "the old apple tree." But music and birds and flowers are not essential, according to Professor Merrill. He emphasizes the utilitarian aspect of the sewage treatment works and does not propose

to have it camouflaged by a veneer of visual beauty. Both authors agree that the true beauty of sewage works structures is expressed by sounds engineering design and efficient operation under conditions which are sanitary, convenient and safe for those who operate the plant, as well as those who visit it. Cleanliness, care and order are considered the chief elements of beauty by Professor Merrill, and not misplaced superficial decorations.

Few, if any, sewage treatment works can be criticized for over-emphasis on beautification, but there may be some reason to doubt whether the plant grounds should be recommended as a public picnic ground, or whether the buildings should be of such a character as to be mistaken for a candy factory, as reported for one rather handsome plant recently installed.

Mr. Luther states in this issue that the superstructure of the Freeport, N. Y., treatment works has been coveted by more than one passer-by for use as a gasoline station. Of course, a gasoline station is inherently not as attractive as a candy factory, but on the other hand, a visitor would be less disappointed if he expected gasoline and found gas, than if he expected candy and found sludge. In both cases possibly the safest course would be to erect a sign along the road advising the public of the character of the superstructures.

Sewage treatment works are usually most popular with the general public when they operate at low cost and without nuisance. The grounds should certainly be graded and sodded, and well-placed clumps of shrubbery are generally advisable, but profusion of flower beds and use of the grounds by picnickers seem hardly warranted. Visitors are usually attracted more by scientific interest in the process than by the appearance of the grounds. Diagrams and exhibits, as described by Mr. Sperry of Aurora, in our July issue, are excellent aids to the general public in understanding the process and the functions of various parts of the plant. Comprehension of the complicated biological transformations involved in sewage treatment is mentally stimulating to an intelligent visitor; olfactory and ocular stimulation are more fitting in a public park.

Proceedings of Local Associations

California Sewage Works Association Fourth Annual Convention

Del Monte, California

September 22, 1931

A meeting of the California Sewage Works Association was held Tuesday, September 22, 1931, at the Hotel Del Monte, Del Monte, California, B. J. Pardee, presiding. The following program was presented:

PROGRAM FOURTH ANNUAL MEETING

September 21–22, 1931, Monterey, California

Monday, September 21

8 A.M.	Meet at City Hall, Salinas.
8–8:45	Visit cannery treatment plant and sewage pumps in town.
9–10	Visit beet sugar plant and waste disposal at Spreckels.
10:15–11:30	Visit Salinas sewage disposal plant.
Noon	Luncheon at Rock Quarry near Watsonville. Guests of Granite Rock Company.
2–3	Visit Watsonville Water Works. Talk on beautification by H. A. Hyde, landscape architect.
3:30–4:30 P.M.	Visit Watsonville screening plant. Return to Monterey.
7	Dinner. Talks by C. C. Kennedy, W. A. Allen, Dr. Carl Wilson and Dr. A. J. Fischer on "Sewage Disposal Out of California."

Tuesday, September 22

9–10 A.M.	Business meeting and election of officers. Committee reports.
10–11:30	Papers on Operation—with discussions. (1) "Progress at Salinas," T. R. Haseltine. (2) "Progress at Griffith Park, Los Angeles Water Department," R. F. Goudey. (3) "Operation of Typical Sewage Disposal Plants in California," E. A. Reinke.

11:30–12	General discussion—manholes, sewer flushing, joints, etc.
Noon	Luncheon to be arranged by local committee.
2–5 P.M.	Joint meeting with Engineers' Section of League of California Municipalities.

Papers:

"Relation of Sewage Works Operator to State Department of Public Health," Giles S. Porter, M.D.

"New Activated-Sludge Plant at Yosemite," H. B. Hommon.

"Sewer Ventilation, Why and How?" David Donaldson.

"What's New in Sewer Pipe Manufacture," A. W. Rawn.

"Odor Control of Fish Canneries," H. D. Severance, City Engineer, Monterey.

"Legal and Other Considerations on Sewer Rentals," W. J. Locke, Secretary-Manager, League of California Municipalities.

Committee Reports

Membership Committee: Mr. Harmon reported 237 members in 1931, showing an increase of 11 over 1930. The following percentages between the different groups were given:

	Per Cent
City, county or state	36
Consulting	17
Operators and inspectors	16
Commercial, main	17
Administrators	5
Laboratory	3
Miscellaneous	6

Standard Report Form: Mr. A. M. Rawn reported no progress in this connection for the present year. He stated that two previous forms were published last year and discussed at the last annual meeting. He advocated a shorter form and urged the trial and use of forms already prepared.

Editorial Committee: Mr. E. A. Reinke cited that the usual publicity work had been accomplished through the publication of the JOURNAL. He announced that the editorial committee had also been made the program committee, and had planned the program for the present meeting. Suggestions on the part of members were welcomed.

Publicity Committee: In the absence of Mr. Philip Schuyler this report was omitted.

Legislative Committee: Mr. J. C. Albers announced that his committee at the present time is working on proposed legislation to come before the next Legislature.

Nomination Committee: Mr. Reinke stated that inasmuch as the regular nominating committee had been 100 per cent absent at the morning session held by the Board of Directors, the following nominations were declared by the Board as a whole, for officers for the ensuing year:

President, the present Vice-President, W. A. Allen; *1st Vice-President,* the present second Vice-President, Mr. John Jacobson; *2nd Vice-President,* Mr. D. McMillan, Ventura, Mr. Fred West, Stockton; *Board of Directors* (5-year term), Professor L. Reynolds, Stanford University; *Board of Control* (2-year term), Professor C. G. Hyde, Berkeley.

Motion to Cast Ballot: Motion was made by Mr. Rawn, seconded and duly carried that with the exception of the Second Vice-President, the Secretary be instructed to cast the regular ballot for all officers nominated. The following vote was obtained for Second Vice-President:

Mr. McMillan	21
Mr. West	15

Election of Secretary-Treasurer: Mr. Reinke was unanimously elected to the office of Secretary-Treasurer for the coming year.

Auditing Committee: An Auditing Committee consisting of Professor Reynolds and Professor Hyde was appointed by the Chairman to make the annual audit of the Treasurer's books. This was done during the course of the meeting, and the books were passed as being correct.

Wire to Mr. Schuyler: The suggestion was made by Mr. Gillespie that a wire be sent to Mr. Philip Schuyler, who is at the present time at Las Vegas, due to illness. The Secretary was so instructed.

Adjournment of Business Meeting: There being no further business to transact, a discussion period was declared in order, preliminary to the rendering of the various reports at the 10 o'clock session.

Discussion

Mr. Rawn favored a discussion of the papers read at the banquet session on Monday, September 21. He called particular attention to Dr. Fischer's report concerning the efficacy of sludge agitation in increasing the production of gas. Mr. Rawn stated that he had read with some interest the result of experimental work performed in Germany along this line, and from this source, he affirmed, comes the chief contention that stirring is of no particular value in sludge digestion. Prominent eastern engineers have likewise placed no particular importance upon the value of agitation, he stated.

Dr. Fischer replied that experimental tests carried on within the last month have indicated conclusively that stirring increases gas production. A series of tests has been conducted at Aurora, Illinois, he stated, showing an approximate increase of 10 per cent in gas production where stirring

is used. Ultimately, of course, the same amount of gas will result in either case, but over a considerably longer period of time in the unstirred tank. More gas is actually produced through short-time digestion. Supernatant liquor is eliminated as a result of violent agitation. The carbon dioxide yield is slightly higher—approximately 2 or 3 per cent. In both instances where stirring was used in conducting the three tests at Aurora, there was actually a 10 per cent increase in gas yield.

Mr. Rawn stated further that while his personal opinion was inclined to be in accord with that of Dr. Fischer, he must recognize the conclusions of the Committee of Sanitation Engineers of the American Society of Mechanical Engineers, which state that although in general stirring produces a more uniform flow and therefore a more adequate control of sludge digestion, due to easier disposal of by-products, the possibility of gas increase, if any, has not been definitely established.

Mr. Haseltine further enlarged upon the subject of gas increase by means of stirring, with the following comments:

When the digester at the Salinas plant was stirred, 200 cu. ft. of gas per day built up to 15,000 cu. ft. This experiment was conducted from October 8, 1930, to the middle of May, 1931. Gas production varied from day to day and was low all the time. The plant was equipped for recirculation of sludge. Sludge was recirculated for one day, at which time a marked increase of gas resulted. Gas production would decrease and then come back. When the pH got up to 7 and stabilization was reached, no effect on gas production was noted, in contrast to the very marked effect when stirring was first started in the digester.

Remarks concerning elimination of scum by recirculation:

MR. GOUDEY: Instead of recirculating sludge, circulate supernatant liquor over the scum.

Determination of sludge blanket in final settling tanks:

MR. JOHN L. MASON: Plants in the East have been built where a number of sludge sampling tubes have been installed on the sides of the sludge tanks.

MR. MASON: In several eastern states there are a number of plants which limit the capacity of Imhoff tanks, or any sludge digestion tank, where 3 cu. ft. per capita cannot be built.

DR. FISCHER: The State Board of Health in New York requires proof in figures before permission will be granted to do this.

Mr. Goudey commented upon factors determining the concentration of sludge at plants in the east, enumerating them as follows:

1. Presence of large quantities of grit
2. Lower temperature
3. Presence of greater amount of mineral matter.

There is no comparison in the size of grit chambers in plants in eastern states and those of the west, he stated. The south has practically the same type of sludge that is found in California.

Mr. Reinke stated that despite his observations he had never yet seen a definition (which meant anything) as to what digested sludge is. He requested a definition of Dr. Fischer. The latter replied (humorously) that "if you can draw sludge out of a tank that is in offensive, it is digested."

Mr. Reinke further questioned Dr. Fischer as to the results of experiments conducted at Salem, Ohio.

"Observations at Salem on waste of excess activated sludge to primary clarifier coincided with observations at Los Angeles. When waste activated sludge was returned to the primary clarifier an average solid content of $9^1/_2$ per cent was obtained, whereas when the activated sludge was pumped directly to the digester the average solid content was between 2 and 3 per cent. Experience with the paddle aerator at this plant showed that a satisfactory effluent could be produced using 0.3 cu. ft. of air per gallon or less, as against 1 cu. ft. per gallon with plain spiral flow aeration."

Reports

The following reports were then submitted:

I. "Salinas Sewage Treatment Plant," T. R. Haseltine-Crist.

II. "Progress at Griffith Park, Los Angeles Water Department," R. F. Goudey-Haseltine, Crist and Fischer.

III. "Operation of Typical Sewage Disposal Plants in California," E. A. Reinke-Haseltine, Goudey and Fischer.

In the general discussion which followed, comments were made by Mr. Clyde C. Kennedy upon the proper disposal of overflow liquor, comparing the methods cited in reports given previously by Dr. Fischer and Mr. Goudey.

Joints: Mr. Perry, representing Sanitary District No. 1, Marin County, spoke briefly upon the difficulty experienced in his District through the use of petrolastic joints, which, he stated, have not proved effective in keeping out roots.

Mr. Goudey explained that frequently air-blown asphalt is penetrated by roots due to the microscopic air bubbles, which permit of plant life.

Mr. Norman W. Kelch, Secretary-Manager of the Clay Products Institute of California, reported progress in connection with the development of a root-proof joint, now being brought about by his company. He stated that they have been working upon the development of a compound which will be successful to prevent root penetration. He continued: "Any such compound would necessarily have to have the following properties:

1. Must be water-tight.
2. Must stick to pipe.
3. Must have flexibility to line.
4. Must keep out roots.

In making an asphalt joint better grades are used. "Petrolastic" is a term which has been misused to indicate bituminous or asphaltic compounds. Therefore, when a petrolastic joint, which was developed by the Standard Oil Company, was put out, this compound contained a filler. Unfortunately, contractors have substituted common roof asphalt at perhaps one-fourth or one-half less cost. Those joints which were made up of cheaper asphalts are responsible for the bad repute of some joints which have permitted short root penetration. We have been trying to get dow to a point where we can definitely determine certain limiting points of penetration with certain types of filters. Some compounds have been developed which can be taken apart and put together with different types of materials, so it will not be an exclusively patented substance. The process employed in manufacturing compounds is similar to that of varnish; the secret of success lies in adding the various materials at the proper time, as well as in the manner of manufacture. A compound might answer the general specifications in every detail—melting point, penetration, percentage of filter—and yet might not be carefully made. Our company is endeavoring to include a germicide in the compound now being developed. So far we have used a compound which has been successful in keeping out roots indefinitely—information concerning it will be made public within the very near future.

Adjournment: The reports having been read and subsequently discussed, adjournment was called at 12 noon, until the afternoon session.

E. A. REINKE, *Secretary-Treasurer*

New York State Sewage Works Association

Fall Meeting

Ithaca, October 16–17, 1931

The Fall Meeting of the New York State Sewage Works Association was held at Ithaca, N. Y., October 16–17, 1931, President J. F. Skinner presiding. The total registration of members and guests was 96, including 16 ladies.

The meeting opened with luncheon at which Hon. Herman Bergholtz, Mayor of Ithaca, welcomed the group and gave them the keys to the city.

Following a brief business meeting the afternoon session was devoted to a paper on "Sedimentation Tank Design and Performance," by Glenn

D. Holmes and a Symposium on Stream Pollution. Mr. Holmes' paper described the experimental work and the actual full design tank performance at Syracuse and was illustrated by numerous charts thrown on the screen.

In the symposium Professor Chamot of Cornell University discussed stream pollution as it affects water purification, Professors J. G. Needham and P. W. Claassen of Cornell University discussed stream pollution as it affects biological life and Dr. Emmeline Moore of the New York State Conservation Department gave a paper on stream pollution as it affects fish life. The papers were illustrated by lantern slides and a lively discussion followed the presentation of the papers.

At the dinner in the evening Dexter S. Kimball, Dean of the Engineering College of Cornell University, was the principal speaker, using the theme of the past and present status of the sanitary engineer. He referred particularly to the short school for sewage works operators that the Association has undertaken and offered the facilities of the university for any assistance that might be needed.

Following the dinner Mr. C. H. Capen of West Orange gave a paper with lantern slides on "Camouflaging Sewage Treatment Plants" and Professor W. C. Taylor of Union College opened a discussion on "Measuring Devices in Sewage Treatment Plants."

Prior to the Saturday morning inspection trip to the Ithaca Sewage Treatment Works and University Water Purification Plant, Professor H. N. Ogden, Messrs., Earl F. O'Brien and Harry Eustance gave a description of the sewage treatment plant and its operation since redesign.

The football spirit of the Cornell-Princeton game was participated in during the buffet lunch in the University Drill Hall and about forty attended the game in spite of the rain.

The local ladies committee provided a splendid sightseeing trip and organ recital for the ladies on Friday and a very instructive visit on Saturday to the Ithaca Reconstruction Home for cases of infantile paralysis.

At the meeting of the Executive Committee it was decided to hold the next short school for sewage works operators at Cornell University at the time of the 1932 Spring Recess.

The Fourth Annual Meeting of the Association will be held in New York City on January 19, 1932.

A. S. BEDELL, *Secretary-Treasurer*

Reviews and Abstracts

H. W. STREETER

Expansion of the Stuttgart Treatment Plant in 1929–1930

By Drs. Maier and Sohler

Gesundheits-Ingenieur, **471** and **486** (Aug. 1 and 8, 1931)

Abstracted by G. P. Edwards

The Stuttgart Treatment Plant in Muhlhausen A. N. was built during the War and put into operation partially in 1916 and completely in 1918. The plant consists of 3 Imhoff tanks, a Neustadt tank consisting of 6 settling tanks and 2 adjacent separate sludge-digestion tanks, a Stuttgart tank with 4 settling chambers and a central digestion tank, all fitted for gas collection, and a trickling filter, later enlarged to treat one-half the flow.

Since 1916, the sewage flow has increased from 15.46 to 26.48 cu. ft. per second. The expansion program calls for additional settling tanks and trickling filters to handle 8.62 cu. ft. per second, enlarged sludge-digestion capacity and pumps for sludge circulation. The new settling tanks, with the digestion tank situated underneath, is rectangular in shape, 92 ft. long, 65.6 ft. wide and 52.5 ft. deep. This great depth was chosen to save space and to obtain the valuable shell limestone for concrete and construction of the sprinkling filters. The lower walls and bottom, which lay completely in the rock, were covered with a 11.8-in. coating of concrete and anchored to the rock. The round iron anchors, 6.5 to 11 ft. long and about 8 inches in diameter, were inserted in 20-in. drill holes and cemented with equal quantities of mortar and cement. The inside of the walls were waterproofed. The settling channels, about 65.5 ft. long, are supported by 3 reinforced concrete supports fixed over the sludge-digestion space. The 5 settling channels are built according to the Emscher design and are 8.2 or 16.4 ft. wide with a depth of 26.24 ft. at the slot. This tank provides a detention period of 2 hours in dry weather with an average velocity of flow of 0.07 to 0.11 in. per second.

The bottom of the sludge-digestion tank, lying under the settling channels, is shaped into two pyramidal sludge sumps. Adjacent to the settling tank is the sludge conditioning tank, which is 26.24 ft. long, 65.6 ft. wide and 52.5 ft. deep, with a capacity of 55,775 cu. ft. The construction is similar to the settling tank. The wall between the settling tank and the

sludge tank is built strong enough for water pressure on only one side because of the possibility that one or the other space may be empty. There are two concrete gas collectors in the conditioning tank, surmounted by 2 large cylindrical gas domes. These domes are made of iron plate about 0.1 in. thick and are mounted on reinforced concrete. They dip at least a foot into the water and are anchored. Filter covers made of porous plates 2 in. thick can be removed at any time without lowering the sludge level. The gas is removed at the highest point of the domes and passes through a gas meter to the compressor, from where it is pumped to the gas works.

A supplementary sludge tank 134,140 cu. ft. in capacity, located between the Imhoff tanks, receives sludge from the digestion chambers of the Imhoff, Neustadt and Stuttgart tanks. The gas collection apparatus consists of 4 pyramidal reinforced-concrete structures upon which the gas domes are mounted.

The sludge pump, a vertical centrifugal pump driven by a 30 hp. rotary motor, is placed in a shaft 49 ft. deep with a rectangular cross section of 13 by 16.4 ft.

Experience for a number of years has shown that for Stuttgart conditions, sprinkling filters are most economical for biological treatment. Two new units to treat 8.62 cu. ft. of sewage per second are about 482 ft. long, 100 ft. wide and about 5.6 ft. high, with a volume of 543,620 cu. ft. Washed and screened shell limestone from 2 to 2.5 in. in diameter is used as filtering material. The underdrains are 4-in. tile pipe. The sewage is distributed by 40 revolving sprinklers each 46 ft. in diameter, and 440 fixed nozzles are placed in the spaces between the rotary sprinklers. The sprinklers work in 5-minute cycles and are fed from two dosing tanks. With a full dosing tank, there is a water head of 3.8 ft. for the fixed nozzle and 2.3 ft. for the rotary distributors. The fixed nozzles form a spray by two streams of sewage impinging upon each other. These nozzles have been very satisfactory as they are cheap and easy to clean. A 2-ft. cement pipe carries the effluent to the Neckar River.

In designing the new digestion tank, 1.06 cu. ft. per capita or 0.01 cu. ft. of solids per capita per day, with 100-day digestion period, was taken as a basis for the calculations. Of this quantity, 0.6 cu. ft. passes to the digestion tank under the settling channels and 0.4 cu. ft. to the sludge conditioning tank.

The cost of the new settling tank and the conditioning tanks was about $115,000.

The supplementary sludge-digestion tank has been in operation since January 11, 1930, and the new settling tank with the sludge conditioning tank since May 23, 1930. One of the sprinkling filters was placed in operation in October, 1929, and the other in 1930.

The reduction of suspended solids in passing through the settling tank amounts to 83 per cent. The sludge from both new tanks is completely digested, deep black in color and has a water content of 79 to 80 per cent. The apparatus for sludge circulation and gas collection has been satisfactory.

In order to break down the scum, 4 nozzles were placed in each gas dome. Settled sewage furnished by a portable high-pressure pump has been satisfactory in controlling the scum. Mixing the scum with the sludge has increased the gas yield from about 0.25 cu. ft. per capita per day to about 0.35 cu. ft. In 1930 about 48,114,000 cu. ft. of gas was produced, for which the municipal gas works pays $0.57 per 1000 cu. ft. The gas contains about 66.7 per cent methane, 11.5 per cent hydrogen and 21.26 per cent carbon dioxide. It has a heat value of about 750 B. t. u.

With a sewage flow of 26.5 cu. ft. per second, or 864,850,000 cu. ft. per year, the annual cost of mechanical purification amounts to about $0.09 per 1000 gallons or $0.23 per capita. With a sewage flow of 17.7 cu. ft. per second or 564,800,000 cu. ft. per year, the annual operating cost of the biological purification amounts to about $0.06 per 1000 gallons or $0.13 per capita.

The sale of sludge for agricultural purposes has decreased greatly during the last year. A side valley of the Neckar River about 1.25 miles distant will be used for sludge lagoons. An experimental submerged contact filter installed in one of the Imhoff tanks seems to have improved the mechanical purification so much that the sprinkling filters could be loaded with several times as much sewage. Conclusive data have not yet been obtained.

Economically Correct Calculations of the Activated Sludge System

BY DR. LEINER, STOLP-RITZOW, POMMERANIA

Gesundheits-Ingenieur, **54**, 405 (June 27, 1931)

ABSTRACTED BY G. P. EDWARDS

The activated-sludge process today is more an economic problem than a technical one, especially in Germany where many of the cities seriously approach bankruptcy. Unit costs differ greatly for different systems. The cheapest are large, relatively deep double tanks. Circular tanks cost more and shallow tanks with surface aeration are still more expensive because of the larger quantity of cement necessary. Walls and hopper bottoms increase the cost.

The amortization period depends on the period of usefulness and not on the considerably longer life period. This useful period can hardly be more than twenty years.

Although service costs in large plants are independent of the system used, in small plants it is important whether the activated-sludge process requires only daily control or also night inspection. Plants with mechanical aeration or using small air compressors require no night service if the electrical control is automatic. The activated-sludge process itself does not demand constant care except when large quantities of injurious industrial wastes are received.

The smaller the experimental plant, the more exact all measurements must be and the more scientific the valuation of all factors. The relations of size, width and depth of the tank react differently with different systems. Large tanks are generally more economical in power since the mechanical and hydraulic resistance is less. This holds true for all systems, the degree of improvement being different for the various systems.

Too small or incorrectly designed secondary settling tanks can cause the best activated-sludge system to fail. In parallel experiments, the relative capacity of the activated sludge and settling tanks should be the same for all. The same shape of tank and slope of wall should also be used. Any method for removing excess and return sludge can be used as long as the same method is used in each. The location of each tank as to exposure to sun, wind and shade should be as nearly the same as possible. Strong winds are favorable in summer but injurious in winter because of the increased cooling.

The small flows in experimental units must be accurately measured. High, narrow weirs accurately calibrated have proven satisfactory. Air measurements must also be made carefully. When the blower is working to capacity, the winter readings can be compared with the guaranteed values. The air required varies not only with the aeration system but also with the nature of the sewage. Air data are seldom transferable from one installation to another. Since accurate data on air requirements are difficult to obtain, it is better to state the power needed. Generally, the power required by any unit can be determined by obtaining the difference between the power required by the entire experimental plant and by the plant without the unit in question. This simple determination is naturally only possible in mechanical plants. When compressed air is used, air measurements must also be given. It is very necessary to carry on the experiments with constant manometer readings.

Experimental results are only relative. The air requirements depend on the peculiarities of the sewage and vary in the same plant with different amounts of industrial waste so that the transference of power data from a small plant to a large one, even in the same place, is permissible only if the experiment is carried out in tanks of about the same size and shape. In general, experimental plants have a power loss of about 10 per cent.

The condition of the process may be recognized from the color of the sludge, the clarity of the effluent and the reserve against overloading. Chemical analyses are better indicators but they have value only if made regularly over a long period. The results of occasional analyses may be misleading.

Data obtained from one system cannot be compared with data from a different system in another city. A comparison of different systems is satisfactory only when the experiments are made under the same conditions.

The gases from sludge digestion and the electrical power obtained from it are of value. Sometimes it is more economical to sell the gas and buy electrical power. When the sale of gas is not possible, electricity may be generated and used about the plant, the excess being sold.

Conclusions should not be drawn from data of experimental or large-scale operation without a study of all conditions. Data are always available. The only question is whether they are right or wrong.

Experiments with Biological Purification at the Tafelwerder Plant in Halle

By Dr. Ing. Heilmann and Dipl. Ing. W. Müller

Gesundheits-Ingenieur, **54**, 559 (1931)

Abstracted by G. P. Edwards

At the present time, sewage is only mechanically purified at the Tafelwerder plant in Halle. The sewage is very concentrated, having an average 5-day oxygen demand of about 410 p. p. m. The settled sewage has an average oxygen demand of 300 p. p. m. After settling, the sewage is discharged to the Saale River, which during dry weather has a flow of about 1306 cu. ft. per second. The average sewage flow is about 14 cu. ft. per second. The Saale River is badly polluted and cannot carry the additional load of the Halle sewage, so that biological purification is necessary. Complete treatment, however, is not essential. In 1927 a submerged contact aerator was installed in the center tank of 3 Imhoff tanks. The tank was filled with twigs and air was furnished through a swinging pipe. The results obtained during two years operation were not satisfactory. This may be due in part to the fact that the settling chambers of the Imhoff tanks were too small.

Early in 1930, 3 experimental activated-sludge tanks, 3.3 ft. wide, 3.9 ft. deep and 27.2 ft. long were built. Compressed air was added at the bottom of each tank through 6 Schumacher filter boxes with the dimensions 3.9 by 7.8 by 1.5 inches. The aerating plate surface in each

tank is about 4.4 sq. ft. or about one-sixth of the total tank surface. The capacity of each tank is about 1450 gallons. Aeration is obtained by the spiral-flow type.

The secondary settling tank is 10.8 ft. long, 10.8 ft. wide and 3.28 ft. deep. The sludge is added at the center and the effluent overflows at the side of the tank. The settled sludge is either returned to the aeration tanks or pumped to digestion tanks.

The aeration experiments were carried out in three ways. In the first experiment, the sewage was aerated without re-aeration of the sludge. With a sewage flow of 0.26 gallon per second and 20 per cent returned sludge, there was a 6-hr. aeration period and a 4-hr. settling period. Two months' operation showed that satisfactory results could be obtained with this sewage flow if the volume of air was maintained at 6 to 8 times the volume of sewage, if the sewage was fresh (methylene blue stability of 1–2 hours) and if the returned sludge was pumped as rapidly as possible from the settling tank so that the solids were not too concentrated. The temperature of the sewage was between 10° and 12° C., rising toward the end of the experiment to 13–15° C. The volume of excess sludge measured after 2 hours settling amounted to about 2 per cent of the sewage flow. The effluent had a 5-day oxygen demand of 10–13 p. p. m.

In the second experiment, the returned sludge was re-aerated. The returned sludge was sent through 2 aeration tanks before mixture and aeration with the sewage. The temperature of the sewage varied between 13° and 17° C. Initially the sewage flow was 0.26 gallon per second but decreased to 0.18 gallon because of unsatisfactory results. Nevertheless the sludge lost its purifying power and the experiment had to be started again. This time the sewage flow was maintained at 0.23 gallon per second. The effluent was satisfactory with an oxygen demand of only 9 p. p. m. The amount of sludge in the sewage aeration tanks varied between 5 and 40 per cent. The best effect was obtained with 15–20 per cent sludge and 8 volumes of air per volume of sewage. The experiment showed that re-aeration of sludge made it more difficult to maintain good activated sludge and required more space.

Pre-aeration of the sewage was tried in the third experiment. Sewage was aerated first alone, then mixed with activated sludge and re-aerated. At first the sewage flow was 0.18 gallon per second and then gradually increased to 0.26 gallon. The amount of activated sludge in the aeration tank rose from 12 to 30 per cent. The temperature of the sewage ranged between 12° and 16° C. and the air used was 10 to 15 times the sewage volume. A satisfactory effluent with an oxygen demand of about 7 p. p. m. was obtained with a sewage flow of 0.18 to 0.21 gallon per second at a temperature of 15–16° C. With a larger flow, more activated sludge and more air is necessary, especially if the temperature is lowered to 12° C.

or less. During the experiment, the sewage temperature decreased to 9° C. and the flow had to be cut to 0.08 gallon per second. Submerged contact aerators were installed to aid the pre-aeration but they were not successful.

From these experiments, it may be concluded that the simple sewage aeration method seemed preferable to the other methods. The Schumacher filter boxes have been satisfactory during the year's operation and have shown no indication of clogging. The air was filtered before use.

It was found necessary to clean the sludge from the walls and bottom of the secondary settling tank every 6 months to prevent sludge from becoming septic. Temperatures below 9–10° C. and above 17° C. seemed to be injurious to the action of activated sludge. The concentration of sewage has a great effect on the action of an activated-sludge plant. If the sewage is diluted by storm water, the absorbing properties of the activated sludge can be increased.

Copper Heating Coils in Sludge Digestion Tanks

BY DR. ING. HEILMANN AND DIPL. ING. W. MÜLLER (HALLE)

Gesundheits-Ingenieur, **54**, 533 (1931)

ABSTRACTED BY G. P. EDWARDS

The secondary digestion tanks of the Tafelwerder Treatment Works in Halle have been heated by hot water passing through copper heating coils. In digestion Tank 1, 984 ft. of copper pipe, about 1-in. in diameter in the form of an Archimedes spiral, were placed on the hopper bottom about 5 in. from the floor. Although it has been claimed that incrustations on the pipe decreases the efficiency of the coils, measurements made from April to October, 1930, and April–May, 1931, show that the heat transferred in each case was 50–54 kg. cal. per sq. meter per hour. Sierp in *Tech. Gemeinde.*, May 10, 1931, showed that iron and copper pipe were strongly attacked by sludge whereas galvanized iron and tinned copper pipe were not corroded. In practical operation, the heating pipes are subjected to different conditions than could be maintained in the experiment. During the passage of hot water through the coil, a sludge film forms on the surface of the pipe which protects it against further attack.

In order to examine the heating coils of secondary digestion Tank 1, the tank was emptied and a section of the pipe cut out. This section was covered with a firm coating of sludge. The coating on the vertical pipe was 0.04 to 0.08 in. thick and on horizontal spiral pipes, about 0.12 in. thick. On the underside of the horizontal pipe the coating reached

a thickness of 0.2 in. Removal of the sludge coating revealed a blue-green film and in places, bad corrosion. The inside also had a blue-green to violet-bronze luster. Copper and carbon dioxide were detected in the blue-green solids. No copper could be found on the surface of the sludge film. The loss due to corrosion for 3.28 ft. of copper pipe about 1-in. in diameter was 0.17 lb. or 7.3 per cent. This corrosion probably did not progress uniformly during the operating period of a year and 9 months. It can be assured that the protecting sludge coating retards the corrosion.

From the fact that the heat transference remained the same from April, 1930, till the present time, it may be concluded that the sludge coating does not increase in thickness. This is probably due to the fact that the coils are about 5 in. from the floor and are washed off by the digesting sludge.

In secondary digestion Tank 2 which has been placed in operation, the copper pipes were tinned to avoid corrosion. The corrosion and heat transfer problems are especially important in this tank as thermophilic digestion will be used. As in Tank 1, the pipes are spiral shaped on the hopper bottom. In all, 1968 ft. of tinned copper pipe about 2 in. in diameter and with a heating surface of 1076 sq. ft. are built in at a distance of about 10 in. from the floor.

Teek Main Sewerage and Sewage Disposal

Anon.

The Surveyor, **80**, 305 (September 25, 1931)

ABSTRACTED BY J. K. HOSKINS

The Teek town council has applied to the Ministry of Health for authority to borrow £86,000 for the construction of main sewerage and sewage disposal works. The scheme includes $3^1/_2$ miles of 30-in. to 36-in. concrete sewers and the replacement of two existing treatment plants by an entirely new one designed to treat a dry weather flow of 1.025 m. g. d. of sewage and trade waste from an anticipated population of 24,000.

The proposed works will treat completely 3 times the dry weather flow and the balance to 6 times this volume in storm water tanks. The general layout consists of:

Detritus Tanks.—Two tanks with sloping bottoms, each 32 ft. long, 9 ft. wide and averaging 9 ft. deep have a total capacity of 21,000 gallons or one-fiftieth of the dry weather flow. They can be operated together or separately and sludged daily by a petrol-driven sludge pump of 500 g. p. m. capacity.

Settling Tanks.—Three settling tanks 150 ft. by 90 ft. in plan and averaging 7 ft. deep have a total capacity of 787,500 gallons or 18 hours flow. The walls will be of brick and floors of concrete with a fall of 4 ft. from outlet to inlet. Scum boards at inlet and outlet ends will reduce turbulence.

Percolating Filters.—Ten percolating filters each 100 ft. in diameter and of 1000 cu. yd. capacity are provided which are designed to treat sewage at the rate of 65 gal. per cu. yd. per day. The walls are to be of brick with tile floors on a concrete base. A 6-in. layer of 2-in. broken brick, 4 ft. of broken sagger or crushed gravel, 1 in. to $^3/_4$ in., and 1 ft. of the same material, $^3/_4$ in. to $^1/_2$ in., constitute the filtering medium. Revolving distributors are to be used.

Humus Tanks.—Two humus tanks of a total capacity of 175,000 gallons or $^1/_6$ the dry weather flow are proposed. Each tank will be 85 to 28 ft. in plan and 6 ft. average depth. A 3-in. suction pipe will remove the humus from a well at the inlet end of each tank. The effluent from the tanks is to be discharged to the River Churnet.

Sludge Drying Beds.—An area of 4200 sq. yd. is provided to handle 5000 cu. ft. of sludge per week or at the rate of 1.2 tons of sludge per day per 1000 population. The beds will have brick sides underdrained with 4 in. open-joint pipe laid in riddled cinders.

Storm Water Tanks.—Accommodation of 525,000 gallons storm water or half the dry weather flow is provided for by 2 tanks 170 by 42$^1/_2$ by 6 ft. depth. Floating arms at the outlet ends empty the tanks after each storm.

Miscellaneous.—A weir equipped with an automatic recorder registers the flow of sewage entering the plant ahead of the coarse bar screens and detritus tanks. Laboratory, storage rooms and a manager's house are provided.

Prevention of Rivers Pollution

BY F. L. WARDMAN

The Surveyor, **79**, 647–648 (June, 1931)

ABSTRACTED BY C. T. CARNAHAN

The chief sources of pollution of streams are domestic sewage, liquid trade wastes and solid wastes.

Sewage disposal works are at times sources of pollution, owing to overworking of plants in handling more sewage than they are designed for, to faulty operation of plants by unskilled or untrained operators, or to improper plant design.

Attention also must be called to pollution arising from the discharge of supernatant tank liquors, sludge bed drainage water or sludge from the treatment plants into the stream, thereby nullifying in part the work done by the treatment plant.

Trained and experienced operators are required to get the best results from the treatment plants and to keep the plants operating at their maximum efficiency at all times.

The discharge of untreated trade wastes and the bypassing of crude sewage into streams is a common and far-reaching source of pollution, as is drainage from unsewered areas. The washing of debris dumped along the river banks into the streams during times of flood is also a source of pollution. The presence of dams or other obstructions may cause an offensive condition in the stream.

The discharge of excess storm water into streams is a periodic source of pollution, which may attain serious proportions and upon which work should be done to reduce this hazard to a minimum. This may be accomplished by treatment of these wastes and by better street cleansing to remove a considerable amount of the polluting materials before they are washed into the drains by the storm waters.

Modern Sanitary Practice

BY CHAS. W. NEWBERY

Extract in *The Surveyor*, **80**, 253–254 (September 11, 1931), of a paper presented at the annual conference of the Sanitary Inspectors' Association

ABSTRACTED BY J. K. HOSKINS

The author stresses the need for coördinated research into various systems of sanitation from the point of view of public health. He suggests that the Public Health Division of the London School of Hygiene and Tropical Medicine should serve as a coördinating center for health activities and research and carry out experiments and investigations looking to the improvement of sanitation procedures and devices. A wide variety of problems are offered for study, including:

Sanitary Fittings.—Improvements in the design of second class fittings for bath, lavatory basins, water closets and sinks are needed, including the weir overflows for these fixtures. The substitution of vitrified porcelain for enamel or painted baths is also desirable. Brass and other metal traps should be improved in shape and interior smoothness to prevent retardation of grease and foul material and also to eliminate unsealing.

Water Closets and Urinals.—The location of water closet rooms to obtain suitable ventilation should be studied and definite rules established

for such procedures. The use of sanitary walls, floors and ceilings to prevent absorption of wastes and permit easy cleaning should be encouraged. The design of suitable urinals is likewise open to improvement. Doors of public conveniences might be fitted with lever opening devices operated by the foot.

Inspection Chambers and Manholes.—The author believes that manholes on drains and sewers could be greatly reduced in number without impairing the efficiency of the sewerage system. Troubles from fouled brickwork and benches, seepage of sewage into the soil through defective brickwork, and ill-fitting frames and covers could thereby be reduced.

Intercepting Traps on house drains are no longer required in many city building codes. Ventilation of sewers through the house drainage system is thereby effected. There is a question of the value of such traps and also of the fresh air inlet shafts.

Need for Uniformity of existing laws and building codes as they apply to sanitary facilities is stressed in the interest of standardization of requirements in adjacent communities.

Treating a Strong Industrial Sewage

Anon.

The Surveyor, **80**, 297–298 (Sept. 25, 1931)

ABSTRACTED BY J. K. HOSKINS

The Yorkshire members of the British Association of Managers of Sewage Disposal Works recently visited two interesting sewage and waste treatment plants described in this article.

Baildon Combing Company Waste Treatment Plant

The wool-scouring liquor is concentrated by evaporation, then centrifuged for grease recovery, from which pure lanoline is obtained. The remaining liquid is treated in a rotary calcinator for recovery of potash, thereby eliminating entirely discharge to the river.

Shipley Sewage Treatment Plant

The previous works, consisting of tanks, contact beds and intermittent sand land filters became outgrown and were replaced by a modern plant designed to treat a dry-weather flow of 1.85 m. g. d. including 1 m. g. d. of liquid trades waste. The works are designed to treat completely 3 times the dry weather flow, the excess up to 4 times this volume to be handled in storm water tanks only. The plant consists of settlement tanks, percolating filters, humus tanks, storm-water tanks and sludge filters.

The 4 sedimentation tanks have a total capacity of 1.39 m. g. or practically 18 hours flow. The tanks are of concrete, have an average depth of 7 ft. and have distributing and collecting channels their full width.

Eighteen of the 22 circular percolating filters are 72 ft. in diameter, have rubble stone walls and employ broken sandstone graded from in. at the bottom to 1 in. at the top as the filtering medium. The other filters use dolomite limestone similarly graded, two of which have a surface layer of destructor clinker. Automatic distributors are employed. The total filtering medium, with a volume of 27,150 cu. yd. provides a dry-weather flow dosage of 68 gallons per cu. yd. per day.

The 3 humus tanks, each 7 ft. deep, have a total capacity of 252,000 gallons. The 4 storm-water tanks hold 700,200 gallons or $9^1/_4$ hours flow. Sludge filters have a combined area of 4700 sq. yd. and humus drying beds 1500 sq. yd. The total pumping capacity is 560,000 gallons per hour.

The reconstruction was performed by direct labor and required about $6^1/_2$ years, employing an average of 40 men. As much of the old plant as possible was retained in the new works, which explains the low cost of £65,400.

The sewage contains all of the spent gas liquors from the city of Bradford, amounting to as high as 2% of the dry weather flow and all of the trades waste of Shipley, resulting in one of the strongest in the country. Because of these and wool scouring wastes, the use of sulphate of alumina, sulphuric acid or copper sulphate is not economically feasible. Plain sedimentation is, therefore, relied upon, although experiments with lime are contemplated. The effluent of the mature filters shows a reduction of 69 per cent in the ammoniacal nitrogen and 79 per cent in the albuminoid nitrogen and 81 per cent of oxygen absorbed from $KMnO_4$ in 3 hours at 98° F.

Report upon the Treatment of Sewage from the Easterly Sewerage District, Cleveland, Ohio

By George B. Gascoigne

Abstracted by Frank C. Tolles

This is the printed form of three reports rendered to the Director of Public Service by George B. Gascoigne, consulting sanitary engineer during 1931. The present document contains 155 pages, $8^1/_2$ by 11 in., with 103 tables, 38 plates and 3 illustrations.

The subject of the report is that of sewage treatment for a major portion of Metropolitan Cleveland inclusive of 40 per cent of the parent city area together with all or part of 9 suburbs. The city is divided into 3 main sewer districts. One of these has an Imhoff-tank trickling-filter

plant which discharges into a local stream. A second district has two-story tanks with seasonal disinfection of the effluent, which is discharged into Lake Erie. The Easterly District, the subject of this report, has had, for nine years, preparatory works consisting of bar gratings and grit chambers, with disinfection during the bathing season.

The report considers the subject from the standpoints of characteristics of the sewage, type of treatment and capacity of needed works. A large part of the text and tabular matter is devoted to the studies of the sewage characteristics. For these there were available testing station data of 1913, demonstration plant results of 1917, operation records, 1924–31, and information from special analytical work in 1931. All of these are quoted in some detail.

A topic of general interest is the discussion of the degree of treatment which is required. The lake is used for recreation, and a proposed water intake is within five miles of the plant site on the lake. Investigations by Whipple in 1904 and Ellms in 1920 show a deterioration in lake waters. Present treatment of the sewage in lake-front plants about Cleveland has been based on sedimentation, generally coupled with some disinfection. The report departs from this precedent by recommending "complete treatment" as offered by the activated-sludge process, the particular process being indicated by restriction of area. A further recommendation is that of pumping the excess sludge to another site for treatment and disposal. One factor in the recommendation for "complete treatment" was that such a degree of treatment would compensate for residual pollution of the lake from surface waste, vessels, etc. Pumping sludge is in the direction of concentrating all sludge from the whole city at one point.

The conclusions of the report relative to basic design are that the initial works should be built for 770,000 people and be capable of expansion to a population of 1,000,000. Sewage flow (average dry weather) is evaluated at 160 gallons per capita per day. The sewage is characterized by a suspended solids content of 200 p. p. m., B. O. D. of 150 p. p. m., iron at 20 p. p. m. and total organic nitrogen of 8 p. p. m. Free fats have been determined at 45 p. p. m.

The treatment works which are recommended provide for utilization and expansion of the present bar grates and grit chambers, and the introduction of grease catchers, pre-settling tanks and aeration and sludge-settling tanks. "Complete treatment" is contemplated for all sewage flows up to $1^1/_2$ times the average. Short time sedimentation is to be provided for additional storm water equivalent to 100 per cent of the average dry weather flow. All sewage and storm water flows beyond $2^1/_2$ times the d. w. f. are to be by-passed after the grit chambers and bar grates. Disposal of the excess sludge is provided by pumping 13 miles

to the existing Southerly Works for digesting, drying and filling. The recovery and utilization of the gas are included. The report includes a study of fertilizer processing by Darwin W. Townsend, but with conclusions which were not deemed favorable to this process at the present time. Another appendix to the report is by Charles H. Hurd on sludge settling. The plant as indicated is now being made effective through contracts for construction.

It is interesting to note that the present project of an activated-sludge plant for Cleveland is to be located at the site of the early Cleveland demonstration of this process in 1916–17.

Data from the report are too voluminous for quotation. However, the following are average returns from several years' operation of the preparatory works:

Coarse screenings ($1^1/_2$- and $^3/_4$-inch gratings)	2.46 c. f. per m. g. av. flow
Grit,	2.19 c. f. per m. g. d. w. f.
Ash—first hopper,	83.0 per cent
Ash—second hopper,	75.9 per cent
Disinfection (seasonal),	69.6 lbs. per m. g.
B. Coli removal,	95.5 per cent

Some Considerations in the Oxidation of Sewage

Discussion of paper of F. R. O'SHAUGHNESSY presented at Association of Managers of Sewage Disposal Works, Birmingham, England, July 3, 1931 (cf. SEWAGE WORKS JOURNAL, **3**, 524–526 (July, 1931)) as reported in *The Surveyor*, **80**, 41–43 (July 10, 1931).

ABSTRACTED BY J. K. HOSKINS

Mr. O'Shaughnessy stated that since writing the paper a comparative study had been made of changes at short intervals in the activated-sludge treatment of a strong sewage liquor after 24 hours settlement by (*a*) the ordinary continuous treatment and (*b*) stage treatment, *i. e.*, by interrupting the process at intervals, separating the liquor and continuing the treatment with a charge of fresh sludge. This study demonstrated the limitations and diminishing effect of the multiple stage treatment. Further investigation of the rates of purification using different proportions of activated sludge showed the diminishing effect of each per cent of sludge as the concentration increased.

Mr. W. E. Speight called attention to the novel method of partial aeration of the settled sewage at Birmingham to reduce aerial nuisance, instead of following the general practice of chlorination in such cases, and of the resulting increased capacity of the sprinkling filters. The rapidity of this oxygen absorption in the first hour was also noted. He

questioned, however, the maintenance of sludge stability after the establishment of a biological balance at plants where sludge reconditioning tanks were not available as at Birmingham. Bulking of sludge is a quite general experience but from the data presented re-aeration might be the remedy. Citing the experience at Bolton with a strong sewage, filtration of the activated-sludge effluent on a sprinkling filter at the rate of 400 gal. per cu. yd. per day had resulted in a clear, well-nitrified effluent, in contrast to the at times unsatisfactory effluent of the activated-sludge process. In the treatment of strong sewages there were limitations to the activated-sludge process requiring prolongation of the detention period which could be overcome by the employment of filters following aeration.

Mr. J. T. Thompson inquired if in starting *de novo* the treatment of Birmingham sewage, Mr. O'Shaughnessy would adopt the bio-flocculation process, to which the reply was given that he would not and that the present installation was the result of local circumstances. As to the relative merits of bio-flocculation and chemical precipitation, Mr. O'Shaughnessy cited the increased benefits of the former procedure.

Mr. L. F. Montfort welcomed the application of mathematical principles to sewage treatment principles and pointed out that the data indicated that excellent results could be obtained by the use of deep filters for treatment of the bio-flocculation effluent, permitting the reduction of construction costs.

Dr. E. Ardern drew attention to the danger of drawing too broad conclusions from laboratory scale experiments. He agreed that operation would be simplified by the use of activated sludge and percolating filters, but that starting *de novo*, it had not been established that such a combination was more economical than the complete activated-sludge process.

New Jersey Agricultural Experiment Station Annual Report of the Department of Sewage Disposal

BY WILLEM RUDOLFS

Bull. **521**, July 1, 1929 to June 30, 1930

ABSTRACTED BY E. HURWITZ

Investigations on the biology of sewage disposal were conducted (1) to determine the underlying principle of the activated-sludge process; (2) to compare the effects of different media on an experimental filter; and (3) to enhance knowledge of thermophilic digestion of sludge.

The activated-sludge studies are yet in their infancy and will require

a number of years for the solution of the various problems connected with the process. No report is made in this bulletin on the progress of these studies. The bulletin includes a preliminary report on the filter experiments and short reports on some of the phases of sludge digestion.

Preliminary Results on Experimental Filters. WILLEM RUDOLFS, H. HEUKELEKIAN AND NOEL S. CHAMBERLIN.—The experimental filter consists of a tank 11 ft. 7 in. in diameter constructed of 2-in. pine boards and divided into 4 water-tight compartments. In one compartment half-inch galvanized-wire mesh was laid at each $^1/_2$ ft. level for a distance of 5 feet. In the other compartments crushed stone, gravel and slag were placed to a level of 5 feet. The specifications for the stone required that 95 per cent be retained on a $1^1/_2$-in. screen and that 100 per cent pass a $2^1/_2$-in. screen. Provision was made for sampling each compartment at $1^1/_2$, $2^1/_2$ and $3^1/_2$ ft. depths and the effluent (5 ft.).

Settled sewage is fed to the filter at the rate of 4750 gallons per day, which is equivalent to 1.96 million gallons per acre per day.

The filter was put into operation Oct. 9, 1929, just before the onset of cold weather. It is estimated from the chemical and bacteriological results that 3 months were required for the filter to be "built up" to a point

TABLE I

Analyses	Average Results, Months	Influent	Crushed Stone Effluent	Slag Effluent	Gravel Effluent	Wire Mesh Effluent
Suspended solids,	1st 3	83	63	63	71	84
p. p. m.	last 3	82	115	106	113	110
	8	83	96	84	90	90
Suspended solids	1st 3	...	20	20	12	+1
reduction,	last 3	...	+33	+24	+29	+28
p. p. m.	8	...	+13	1	+7	+7
Suspended solids	1st 3	...	24	24	14	+1.2
per cent reduction	last 3	...	+40	+29	+35	+33
(+ = increase)	8	...	+16	+1.2	+8.6	+8.6
Biochemical oxygen	1st 3	161	75	74	88	121
demand, p. p. m.	last 3	226	104	71	117	161
	8	173	103	80	109	131
Biochemical oxygen	1st 3	...	76	87	73	40
demand reduction,	last 3	...	122	155	109	65
p. p. m.	8	...	70	93	64	42
Biochemical oxygen	1st 3	...	47	54	45	25
demand reduction,	last 3	...	54	67	48	29
per cent	8	...	41	54	37	24
Dissolved oxygen	1st 3	35	53	65	62	54
per cent	last 3	32	52	54	45	43
saturation	8	36	51	59	55	50
Dissolved oxygen	1st 3	...	18	30	27	19
increase per cent	last 3	...	20	22	13	11
saturation	8	...	15	23	19	14

of normal operation. Consequently, comparison of the different filter media are divided into 3 periods: (1) first 3 months; (2) last 3 months; and (3) the intervening 2 months' period. Table I gives results of analyses of the influent and 4 effluents for suspended solids, B. O. D. and D. O.

The greatest percentage removal of suspended solids occurred during the first few weeks of operation. Of the different media the slag removed the greatest amount of suspended solids. Ease and rapidity of sloughing was greatest in the crushed stone and least in the slag.

The average B. O. D. reduction was greater during the last 3-month period than during the first. For the whole 8-month period the slag gave best results, followed by stone, gravel and wire mesh in order named.

Changes in the nitrogen cycle at different levels of the filters are given in Table II.

The table shows that the percentage ammonia reduction is greatest in the slag, followed by the stone, gravel and wire filters. Ammonia reduction was the same in all stone media in the first $^1/_2$ ft. of filter. With increasing depth, variations occurred.

The slag medium produced considerably more nitrites than the other media. Nitrate production was greatest at levels lower than $1^1/_2$ feet.

The results show that the slag medium produced more nitrate than the others. However the shapes of curves showing nitrate production of the different media at various depths indicate that in no case was the maximum efficiency reached.

Bacterial analyses made over the 8 months during which the experiment was conducted, indicated that all stone media are practically equally efficient in *B. coli* removal.

The observations made in the course of the filter experiments may be summarized as follows: In the process of "building up" the zone of nitrification moved downward. Considerable quantities of ammonia were lost into the air. The greatest removal of suspended solids occurred in the roughest medium, whereas the greatest ease of unloading was exhibited by the smoothest material.

Considerable direct or non-biological oxidation took place as indicated by a B. O. D. reduction of 25 per cent on the wire mesh. Most of this reduction must have been due to direct oxidation.

The effectiveness of the filters as a straining device was greatest in the upper layers; this holds true for suspended solid removal, B. O. D. and *B. coli* reduction.

Although increased loads produced a somewhat poorer effluent, the percentage B. O. D. removal varied directly as the load on the filter.

Reaction Adjustment of Acid Sludge. WILLEM RUDOLFS.—Occasionally it happens that sludge for digestion has a pH value lower than 6.1. To complement the curves given in a previous paper showing the amounts

TABLE II

	Period, Months	Influent	Crushed Stone				Slag				Gravel				Wire	
			1.5 Ft.	2.5 Ft.	3.5 Ft.	5 Ft. Eff.	1.5 Ft.	2.5 Ft.	3.5 Ft.	5 Ft. Eff.	1.5 Ft.	2.5 Ft.	3.5 Ft.	5 Ft. Eff.	Eff.	
Ammonia, p. p. m.	1st 3	27.7	25.3	24.0	21.8	23.3	24.8	21.9	21.7	21.2	25.2	25.6	25.1	23.9	24.4	
	last 3	30.5	25.8	21.8	22.2	15.3	25.4	22.6	17.3	9.7	28.5	25.0	22.9	15.8	23.1	
	8	28.1	24.9	22.8	20.6	19.6	24.4	20.7	19.7	16.4	24.5	24.2	23.3	20.3	23.3	
Ammonia reduction, p. p. m.	1st 3		2.4	3.7	5.8	4.4	2.9	5.8	6.0	6.5	2.5	2.1	2.6	3.8	3.3	
	last 3		4.7	8.7	8.3	15.2	5.1	7.9	13.2	20.8	6.0	5.5	7.6	14.7	7.4	
	8		3.2	5.3	7.5	8.5	3.7	7.4	18.4	11.7	3.6	3.9	4.8	7.8	4.8	
Ammonia reduction, per cent	1st 3		8.8	13.5	21.2	16.0	10.5	21.2	21.6	23.5	9.0	7.5	9.5	13.7	12.0	
	last 3		15.7	28.1	27.5	50.6	16.9	26.1	43.6	68.3	20.1	18.4	25.4	48.4	23.7	
	8		11.4	19.0	26.7	30.0	13.2	26.3	30.4	41.7	12.8	13.7	17.0	27.8	17.0	
Nitrites, p. p. m.	1st 3	0.06	0.18	0.63	0.93	1.1	0.42	1.7	2.6	4.1	0.11	0.35	1.1	1.5	0.08	
	last 3	0.11	0.30	0.72	0.94	1.0	0.34	0.65	0.81	0.84	0.19	0.39	0.83	0.98	0.15	
	8	0.10	0.22	0.62	0.88	1.1	0.35	1.2	1.7	2.5	0.16	0.36	0.92	1.2	0.12	
Nitrates, p. p. m.	1st 3	0.82	0.78	1.3	2.8	2.6	0.98	3.2	3.7	6.5	0.77	1.1	1.3	2.1	0.75	
	last 3	1.00	1.80	3.7	5.8	9.7	1.40	4.7	6.8	9.6	0.98	1.7	3.2	6.5	0.78	
	8	0.94	1.10	2.1	3.8	5.0	1.20	3.9	4.7	7.1	0.87	1.3	2.2	3.6	0.81	

of lime necessary to adjust the pH for values from 6.1 to 7.2, another set of curves was constructed to show at a glance the amounts to be added to adjust the pH to 7.2 from values lower than 6.1. It is essential in adjusting the pH to mix the lime thoroughly, adding only small quantities at a time. Since lime has a tendency to stimulate the growth of acid-producing organisms it may be safer when the pH is below 6.0 to empty the tank and start anew.

Distribution of Protozoa before and after Sloughing. WILLEM RUDOLFS.—The fluctuation of the protozoa most commonly found on filter beds was studied. The fluctuations were correlated with the amounts of film on the stone. It was found that the numbers of organisms in the film around the stone do not increase in proportion to the increase in thickness of the film. As soon as the thickness of film decreases the numbers of organisms increase. The change in numbers of organisms is rapid and occurs throughout the bed. Free-swimming organisms are found in the effluent sooner than the stalked types.

Notes on Supernatant Liquid and Digestion. WILLEM RUDOLFS.—The withdrawal of supernatant liquid had a somewhat detrimental effect on sludge digestion as evidenced by slightly lower pH values. However the reduction of solids was as great in the sample from which the supernatant liquid was withdrawn as in the samples left intact.

Supernatant liquid after standing in contact with fresh solids contains substances difficult to decompose. The time required to bring the pH of the liquid to 7.8 varied directly with the age of the liquid, that is, with the time the liquid stood in contact with fresh solids.

Seeding the fresh supernatant liquid with some that had already reached a pH 7.6 speeded up the reaction.

Replacing part of the supernatant liquid with distilled water ("washing") did not speed up digestion and consequently was of no material aid.

Experiments with Trenton Sewage Sludge. WILLEM RUDOLFS AND I. O. LACY.—Sewage solids collected from the Trenton plant, which receives considerable and varied trade wastes, were digested. Part of these solids was limed and part was seeded with ripe sludge. It was found that the limed portion produced more gas than the control but the reduction of solids was less. The seeded material digested rapidly. The total gas production from these solids was less than from strictly domestic sewage, due possibly to the high iron content of Trenton sewage.

Coöperation with the State Department of Institutions and Agencies. G. M. RIDENOUR.—The station carried on investigations of sewage problems at various state institutions, recommending changes, designing and assisting in the operation where necessary.

Sludge Disposal Method in Two Similar Sewage Plants

BY E. G. MCCONNELL

Eng. News-Rec., **107**, 247 (1931)

ABSTRACTED BY G. P. EDWARDS

An unusually good opportunity to compare two common methods of sludge disposal is afforded in 2 three-year old activated-sludge plants of much the same design at Charlotte, N. C., where filtration of sludge is practised at one plant and digestion at the other. The two plants handle practically the same amounts of sewage, are located within 3 miles of each other and are operated under the same supervision.

The Irwin Creek plant is provided with a manually cleaned coarse screen, a mechanically cleaned grit chamber, 6 1-m. g. d. ridge-and-furrow bottom aeration tanks, 6 mechanically cleaned final settling tanks and vacuum filters for the excess activated sludge. Only 4 of the 6 aerating and settling units are in operation.

The Sugar Creek plant has a mechanically cleaned coarse screen and grit chamber, mechanically cleaned pre-settling tank, 5 mechanically cleaned final settling tanks, covered sludge-digestion tanks with a sludge capacity of 4.5 cu. ft. per capita and open sludge-drying beds with an area of 1 sq. ft. per capita.

Ferric chloride is added to the sludge before filtration at the Irwin Creek plant while at the Sugar Creek plant lime is added to the sludge before it goes to the digesters. Digestion gas is used at the latter plant for power production and the cooling-jacket water, together with the water from a heater placed on the exhaust, is used for heating the digesters. The cost of maintaining the engine practically wipes out the value of the power produced.

The Irwin Creek plant serves an estimated connected population of 25,000. The average sewage flow during 1930 was 2.75 million gallons per day, of which about 7 per cent is trade waste, chiefly from laundries and a hosiery mill. The Sugar Creek plant had an estimated connected population of 50,000 and an average flow during 1930 of 3.9 m. g. d. of which about 15 per cent is industrial waste from laundries, textile mills and a cotton-oil refinery.

At each plant, the sludge is returned by slow speed centrifugal pumps. Considerable difficulty has been encountered with "bulking" sludge, which is probably proportional to effective air control. The oxygen demand of the raw sewage at each plant averages 200 p. p. m. It has been found that approximately 0.2 per cent of dry solids in the aeration tanks give the best results. If less than 0.15 per cent solids are present, the effluent tends to suffer in quality. A concentration in excess of about 0.3 per cent

requires an increased power demand and slightly interferes with settling efficiency in the final settling tanks.

The sanitary quality of the effluents from each plant is satisfactory. The Irwin Creek plant effluent has an oxygen demand of 26 p. p. m. while at the Sugar Creek plant it is 19 p. p. m. The nitrate-nitrite nitrogen is considerably higher in the Sugar Creek effluent.

Comparative cost figures show that the slight saving of $2.66 per million gallons in operating cost in favor of the digestion process is practically wiped out by the additional fixed charges for this type, leaving a net saving of only $0.53 for the digestion process. It seems that the chief items to consider in the choice between the two sludge disposal methods would be plant construction costs and facilities for disposition of the sludge product.

Molds Successfully Deodorize Undigested Sewage Sludge

BY C. G. WIGLEY

Eng. News-Rec., **107**, 448 (1931)

ABSTRACTED BY G. P. EDWARDS

A process for encouraging the growth of molds in partly dried sludge is being developed at the treatment plant of the Atlantic City Sewerage Company for deodorizing fresh sewage solids. Atlantic City sewage is completely domestic in character with the exception of small quantities of cleaning and dyeing liquids. The treatment consists of grit removal and settling, with no provision for sludge digestion. The solids are pumped daily from the settling chamber to shallow sand beds where they are drained to about 95 per cent moisture. The sludge is then removed to an adjacent sandy area and allowed to dry further. Despite its undigested condition, there is no nuisance developed by the stored material. The deodorizing effect of molds or mildew on sewage solids was noticed. In order to encourage the growth of molds on fresh sewage sludge, one-sixth of the total sludge is removed to a drying bed, air dried to 20 per-cent moisture and then broken up. After grinding, it is stored in a dark building in shallow piles. Under proper conditions, the mold soon penetrates the mass. Since mold spores are abundant in the air of the building, after it has once been used for this purpose, seeding is unnecessary. During the process, the material may generate considerable heat but no disagreeable odor.

The cured sludge usually has a musty odor. An analysis of the fertilizing constituents is as follows:

	Per Cent
Total nitrogen	1.96
Available nitrogen	0.76
Phosphoric acid	0.62
Potash	0.13
Organic material	35.9

It is now being sold as fertilizer in Atlantic City for $20 a ton.

Remodeling a 34-Year-Old Sewage Treatment Plant

BY HARRY W. EUSTANCE

Eng. News-Rec., **107**, 525 (1931)

ABSTRACTED BY G. P. EDWARDS

Ithaca, N. Y., a city of 20,708, is located at the head of Cayuga Lake. The original sewage treatment plant, providing for plain dilution, was built in 1897. Septic tanks of the Cameron type were installed in 1909. Insufficient treatment, inadequate outfall capacity and pumping difficulties led to a decision in 1927 to convert the plant to the plain sedimentation and separate sludge-digestion type, to construct a new 30-in. cast iron outfall pipe with a capacity of 7000 g. p. m. and to install new pumping units. Two of the old septic tanks were remodeled into plain settling tanks giving a $3^1/_4$-hour detention period with the present dry-weather flow. The three remaining tanks are used for sludge storage. The settled sludge is transferred to a heated cylindrical tank 55 ft. in diameter and 19 ft. deep, equipped with a mechanical sludge scraper at the bottom and scum breaker above. Gases produced are collected and burned under a hot-water boiler that is connected to heating coils in the tank walls. The supernatant liquor is re-settled and the digested sludge is dried on sand beds. Based on a future population of 32,000, the digestion tank provides 1.4 cu. ft. of volume per capita and the drying beds 0.4 sq. ft. of area per capita.

Operation of the Activated-Sludge Plant at Elyria, Ohio

BY FRANK WOODBURY JONES AND JAMES R. COLLIER

The American City, **45**, 103–106 (August, 1931)

ABSTRACTED BY E. HURWITZ

The sewage treatment plant at Elyria, Ohio, is an activated-sludge plant with separate sludge digestion. It is designed for a population of 36,000 but at present is treating only 21,000. Sewage enters the plant

through $1^1/_2$-inch bar gratings. It then flows through the grit chambers, primary settling tanks, aeration tanks and final settling tanks.

The two primary settlers are Imhoff tanks 62 by 31.5 ft. in plan and 27 ft. deep. At normal flow, they have a detention period of one hour. They are capped for gas collection.

There are four aeration tanks of the spiral-flow type. Each of these is 80 by 21 ft. in plan and 15 ft. deep. The aeration period at normal flow is about four hours.

The final settling tanks, of which there are two, are of the Dorr type, 45 ft. square and 12 ft. deep.

The two separate sludge-digestion tanks are conical at the bottom. They are 50 ft. in diameter and have a side depth of 20 feet, with a total depth of 32 feet. These tanks are fitted with floating covers.

Pumps and piping are so arranged that excess activated sludge may be pumped to the primary tanks by way of the incoming sewage, or direct to the sludge compartments, or directly into the digesters or onto the sludge beds. The primary sludge can be pumped into the digesters or onto the sludge beds; and sludge from the digesters may be discharged onto the beds or back into the primary tanks or digesters for further conditioning. The supernatant liquor can be pumped onto the sludge drying beds or back into the primary settlers.

There are 8 glass-covered sludge beds, with a capacity of 0.56 cu. ft. per capita based on 21,000 population.

Some difficulty was experienced in putting the plant into operation because of blanking of the fitros plates by iron from pickling liquors. Provision was made to treat these wastes at the source and since then the plant has operated satisfactorily.

The total gas production for 6 months, June to December, 1930, was 2,287,400 cu. ft., or 0.6 cu. ft. per capita per day. The reduction in volatile matter of the fresh solids was from 80 per cent, as deposited in the primary tank, to 59 per cent when removed to the digesters. There was a further reduction to 43 per cent in the digesters. The sludge from the primary tank as removed to the digesters averaged 4.0 per cent solids; when placed on the beds from the digesters, 7.1 per cent solids.

Analyses show the per cent reduction effected during the months from June to December, 1930.

	Raw Sewage	Settled Sewage	Final Effluent	Per Cent Removal, Primary Treatment	Per Cent Removal, Complete Treatment
Suspended solids	169	71	12	57	93
B. O. D., 5-day	192	116	6.8	40	96.5
NH_3	17.3	18.1	0.6	−4.6	96.5
Org. N	7.4	5.8	2.4	21.6	67.5
Alkalinity	196	218	88	−11.2	55

A Model Sewage Treatment Plant with Attractive Surroundings

BY SAMUEL A. GREELEY

The American City, **45**, 88-92 (Oct., 1931)

ABSTRACTED BY E. HURWITZ

The Peoria, Ill., sewage treatment plant is of the activated-sludge type, with separate sludge digestion. It has a capacity of 22.0 m. g. d. which provides for the sewage from 140,000 population at 14.0 m. g. d. and in addition 8.0 m. g. d. of industrial waste.

The sewage enters into a screen well and passes through a $2^5/_8$-in. mechanically cleaned bar screen. It is pumped to the $1^1/_2$-in. bar screens and then flows into the grit chamber. The grit chamber has two channels, each of which is 40 ft. long by 9 ft. wide, with an average liquid depth of 5.7 feet. The channels are equipped with Link-Belt mechanism for removing and washing the grit.

From the grit chambers the sewage flows to 4 primary settlers equipped with Dorr traction-type apparatus for removing sludge and floating matter. These tanks are 65 ft. square with a liquid depth of 10 feet.

Aeration is provided in 4 tanks of the spiral-flow type. These tanks are 190 ft. long, with three flowing-through compartments, each 23 ft. wide with a liquid depth of 15.5 feet. The approximate displacement period is 5 hours at 22 m. g. d. and 20 per cent return sludge. Excess activated sludge is pumped either to the influent channel or direct to the sludge digestion tanks.

The final settling tanks are of the Dorr type and have an area sufficient to give a settling rate at 22.0 m. g. d. of 1200 g. per 24 hours per square foot.

The sludge-digestion tanks are 85 ft. in diameter by 29 ft. deep and have a capacity of 0.66 cu. ft. per capita for an estimated population equivalent of one million. There are 4 of these tanks and each is equipped with sludge-removal mechanism, heating coils, etc. A special sludge-control house is provided, equipped with pumps for handling and circulating the sludge and hot water for heating the tanks. Storage tanks with a total capacity of 850,000 cu. ft. are used for holding the sludge over winter if necessary.

There are 28 drying beds, each 50 ft. wide and 200 ft. long, equipped with narrow-gauge track for removal of sludge. These beds have a capacity of 0.25 sq. ft. per capita based on one million population.

A small trickling filter with revolving distributor was included in the layout of the plant.

The buildings are substantially and attractively constructed and the grounds are landscaped. The cost of the plant including levee and all plant structures was $1,700,000.

A completely equipped laboratory is provided and analytical records started on the first day sewage was turned into the plant. Typical analyses for the summer of 1931 are given below:

	Influent	Effluent
Suspended matter	235	12
B. O. D., 5-day, 20° C.	174	6.0
Org. N + NH_3	25.0	2.4
Nitrates + nitrites	0.0	6.4

Some Important Phases of Sewage Chlorination

BY HARRY E. JOHNSON

Water Works and Sewerage, **78**, 227 (1931)

ABSTRACTED BY G. P. EDWARDS

The efficiency of the chlorination of sewage for the purpose of oxygen-demand reduction or odor control depends upon the point of application, the method of application, the pH of the sewage and the presence of industrial wastes. Chlorine should be added to the sewage as far ahead of the treatment plant as is practicable without re-seeding the chlorinated sewage from laterals below the point of application.

Chlorine in high concentrations tends to react with organic matter in sewage to a degree far in excess of the apparent chlorine demand. This excess chlorine reacts chemically with humus matter compounds which have slight if any disinfectant action. With solution-feed equipment, it is necessary to feed the chlorine solution through an efficient distributor so that it is instantaneously applied to all parts of the sewage flow. Back eddies permitting the sewage to come in contact with the chlorine more than once must be avoided. A new direct "Impulse" or "Impact" diffusor operating with a very low water consumption on the principle of an atomizer has been very satisfactory.

Experiments with sewages adjusted over a range of pH 5.0 to 9.0 have shown that chlorine consumption is lowest at pH 7.0 with lime-chlorine mixture, hypochlorous acid and chlorine water. Below pH 7.0, lime-chlorine mixtures were most economical with hypochlorous acid next. Above pH 7.0, hypochlorous acid and chlorine water were somewhat more economical. The effectiveness of sterilization was greatest at pH 7.0 with all three reagents although the order of economy per unit of chlorine was (1) hypochlorous acid, (2) chlorine water, (3) calcium hypochlorite. In

acid sewages, lime-chlorine mixtures would be most effective and with neutral or alkaline sewages, hypochlorous acid would be best.

Industrial wastes such as ammonia-still liquor or meat-packing wastes, which have a high chlorine demand and which produce still greater chlorine demand when discharged into sanitary sewers due to the decomposition of sulphur compounds, should be eliminated at the source, if possible. Wastes which have a high chlorine-consuming capacity but do not decompose in the sewer may be treated either at the source or later. Those wastes which have no chlorine demand in themselves but contain sulphur compounds which break down in the sewers, increasing the chlorine demand, require treatment at the source.

Chlorination costs can be reduced materially if some study is given the existing situation and corrective measures are adopted.

Infiltration Very Small in Westchester Sewer

BY E. C. HALLOCK

Public Works, **62**, 17 (August, 1931)

ABSTRACTED BY C. T. WRIGHT

The total infiltration in the Mamaroneck Trunk Line sewers of the Westchester County Sanitary Commission, as measured prior to opening for use, is so much smaller than required that the system will take care of a greater load than it was designed for.

As practically the entire line was far below ground water level, the utmost care was taken to insure a permanent and tight line and to prevent seepage into the sewer.

Some of the sewers were built of cast iron pipe from 14-in. to 24-in. diameter, 12-ft. lengths, laid on crushed stone with a vitrified tile underdrain. A 40-lb. air test was applied on all cast iron pipe, about 23,000 ft. of which was used.

Most of the sewers were, however, from 24-in. to 66-in. diameter. Here 8-ft. lengths of reinforced pre-cast concrete pipe were used, laid on a concrete cradle, with crushed stone and a vitrified tile underdrain under the cradle. About 66,000 ft. were built. For testing, a 4-ft. internal head was placed on all concrete pipe before backfilling. The average leakage was only a fraction of the amount allowed under the specifications.

The total infiltration allowed was over 725,000 gallons for 24 hours, whereas the actual infiltration showed a maximum of 86,000 gallons for 24 hours.

The methods of making up the construction joints and the specification for leakage are given in detail and illustrated by sketches.

A New Treatment for Meat Packing Wastes

BY W. P. FULLEN AND E. N. ANDERSON

Public Works, **62**, 25–26 (July, 1931)

ABSTRACTED BY C. T. WRIGHT

A survey of this field will reveal that standard methods of sewage treatment are inadequate for packinghouse wastes. All methods depending upon biological activity are more or less interfered with in these wastes by the high salt and fat content.

Investigations conducted at the plant of G. A. Hormel & Co., at Austin, Minn., have been directed toward finding ways and means of recovering the protein from the sewage, so that its value can be used to defray operating expenses. In order to be able to recover nitrogenous material so that its value can be used to defray operating expenses, it is necessary to remove it in a more or less unchanged condition.

Any method of chemical precipitation to be successful, not only must remove suspended organic matter, but also must remove the dissolved packinghouse sewage, which contains on the average of about 100 p. p. m. of nitrogen in the form of organic matter.

Laboratory observations indicate that chlorine in sufficient quantities can be used efficiently and economically in the precipitation of tanks effluent. On the basis of the findings, a plant was constructed to treat the wastes.

In this newly constructed plant the raw sewage coming from the packing plant first enters a small Dorr clarifier, with a detention period of 20 minutes. During this short period large particles of organic matter settle and the majority of the grease comes to the surface and can be skimmed off. The effluent from this Dorr clarifier is treated with chlorine and after suitable agitation is run into a second clarifier, where the precipitation takes place. Detention in the second clarifier is longer than in the first. From this second clarifier the sludge is removed to be dewatered, and then dried in the regular tankage drier.

The dried sludge has a protein value ranging from 40 to 50%, or an ammonia content, from 9.3 to 9.5%. The sludge at first contains about 90% of water. This water content is reduced to 75% very readily.

The sewage from the packinghouse is disposed of in the Cedar River, between two dams which are 2 miles apart. The plant sewage in the past was discharged just below the upper dam and previous to the installation of the new plant odors were always prevalent. Floating sludge was noticeable on the surface of the water at all times. The B. O. D. of the

river water just below the discharge of the packinghouse sewer was approximately 200 p. p. m.

The plant has been in operation for a period of 5 months; during this time conditions in the river have improved materially. The B. O. D. of the river water has been diminished to less than 20 p. p. m. and sludge in the river has practically disappeared.

Preliminary estimates indicate that the value of the sludge figuring nitrogen at market value, will pay for the cost of the chlorine, cost of operation, including labor and power and interest and depreciation on the plant at the rate of 12 per cent.

The chlorine consumption does not exceed 2000 lb. per day to remove the desired amount of sludge.

Note: Also see THIS JOURNAL, **3**, 488–501 (July, 1931).

Remodeling Providence Sewage Treatment Works

BY F. S. NOLAN

Public Works, **62**, 25 (August, 1931)

ABSTRACTED BY C. T. WRIGHT

Providence, located at the head of Narragansett Bay, has a population, largely industrial, of about 270,000 people living in an area of approximately 19 square miles.

The present sewage treatment plant was built in 1897, to dispose of a maximum of 30 million gallons a day by chemical precipitation. It has for the past several years been treating about 36 million gallons. Operating expense of the present system for chemicals alone amounts to nearly $200 daily, $150 of this being used for chlorine and $40 for lime. The engineers estimate that this sum will cover the electrical expense of operating the new system.

In the new system, chemical precipitation will be replaced by the activated-sludge process. The raw sewage will pass first through 2 mechanically-cleaned screens, each 6 ft. wide with $^3/_4$-in. openings between bars, whence the screened sewage will pass through 2 detritors. The screened sewage then will flow to 2 primary settling tanks, having a total area of 20,000 sq. ft. and equipped with revolving sludge scrapers. The detention period at average flow will be 45 minutes, and with a maximum flow, 30 minutes.

The effluent from the primary tanks then passes through a mixing channel, where it will receive returned sludge from the final settling tanks, and the mixed liquor will pass through spiral-flow aeration tanks in which

diffused air will be used as a means of aeration and agitation. Figuring about 25 per cent returned sludge, with a flow of 32 m. g. d., a detention period of 6 hr. will be provided; or with a flow of 48 m. g. d., and the same percentage of returned sludge, detention will be reduced to 4 hours.

The aeration-tank effluent will be clarified by sedimentation in 5 final tanks, which are equipped with revolving sludge scrapers. These tanks allow a detention of $1^1/_2$ hours at the average flow.

The final effluent will be chlorinated before passing into tidewater. The sludge will be dewatered (the method of dewatering has not yet been fully decided upon) and the cake will be carried by scow to dumping grounds in the lower bay.

Parts of the old plant are being transformed into sections for the new system thus effecting a considerable saving. The cost of the activated-sludge plant when completed will be about $20,000 per million gallons, or about one-third the price of an entirely new system.

The Treatment and Disposal of Sewage from a Small Institution

BY MARION L. CRIST

Waterworks and Sewerage, **78**, 247 (1931)

ABSTRACTED BY G. P. EDWARDS

The treatment of sewage from the Santa Barbara County (Calif.) Hospital and Farm consists of preliminary settling and separate sludge digestion with activated sludge for final treatment. No diluting water is available so that a stable effluent is necessary. The average daily flow is about 16,000 gallons. The settled sewage is aerated 10 hours in a circular tank provided with a Watsco (Hardinge) aerator, which consists of a screw pump in the center tank with suction just below the surface and discharge at the bottom of the tank. The injected air is carried to the bottom and rises through the mixed liquor contents of the tank. About 4 cu. ft. of air per gallon of sewage is used. It has been impossible to build up a heavy sludge, possibly because of the great variation in quality and quantity of sewage. The solid content of the aeration tank is kept very low in order to keep the sludge from "bulking." In passing through the plant, the oxygen demand was reduced from 367 to 4.5 p. p. m. and the suspended solids from 188 to 50 p. p. m. Power consumption approximates 5 hp. continuously, which at existing rates amounts to about $25 per month. The operating expense of a plant as small as this one is more or less negligible.

Industrial Waste Disposal and By-Product Recovery

Chem. and Met. Eng., **38**, 498–552 (Sept., 1931)

ABSTRACTED BY E. HURWITZ

The September issue of *Chemical and Metallurgical Engineering* is devoted to articles on waste disposal and recovery of by-products and to the closely allied subjects, water purification and stream pollution. The introductory article, "*Industrial Waste Disposal as a Chemical Engineering Problem*," by *E. B. Besselievre*, points out that because waste products are almost invariably the result of some chemical process the problems connected with them are such that their solution falls upon the chemical engineer. In attacking these problems the chemist or chemical engineer must bear in mind that the ultimate result must be an economic possibility for the plant owner; it must take cognizance of his rights to pursue his business with the least hindrance and yet it must show proper consideration and respect for the comfort and health of everyone affected. In many cases waste product treatment has resulted in waste product recovery with a profit to the industry.

"*Stream Pollution*" from the standpoint of the sportsman, industrialist and sanitarian is discussed by *Abel Wolman*. In general the harmful effects of pollution are (1) contamination of potable water supplies with damage to health; (2) the development of nuisances objectionable to public health and comfort; (3) damage to property with depreciation of values; (4) the destruction of fish and other natural fish life; (5) damage to live stock; (6) interference with recreational facilities; (7) interference with commercial uses of a stream; (8) specific toxic effect due to particular industrial wastes. In recent years there has been a marked growth of societies interested in cleaning up streams for the protection of fish and game. The methods of these groups have not always been impartial or informed but of late they have learned that the problem is a complex one, requiring careful, scientific study and coöperation between the administrative forces, the organizations interested in protection of the streams against pollution and the industry. Industry, too, has come to understand that indiscriminate discharge of waste into the nearest water course is unwarranted and that recovery or treatment of wastes is an integral part of the cost production.

The improvements in sewage treatment processes made possible by chemical engineering science are discussed by *F. W. Mohlman* in "*Modern Sewage Disposal Exemplifies Chemical Engineering Progress.*" Profound changes have occurred in the technique of sewage treatment in the last five years, particularly with respect to the use of mechanical devices and the collection and use of the combustible gas produced by decomposition of sewage sludge.

Complete treatment of sewage can be obtained by either the trickling filter or by the activated-sludge process. Very little improvement has occurred in the construction or operation of trickling filters. The activated-sludge process, on the other hand, has seen numerous improvements. It is now customary to provide preliminary settling tanks before the aeration tanks; it has been found to be more efficient and economical to place the porous plates at the side of the tank, forming a spiral-flow system; numerous mechanisms have been tried to provide mechanical mixing of the sludge with the sewage to cut the cost of expensive mixing by compressed air.

The disposal of the sludge is still the major problem in sewage disposal. Recovery of a commercial fertilizer has not been found to be profitable. The tendency now is toward digestion of mixed fresh solids and activated sludge and drying of the digested sludge on sand beds. The dried sludge is disposed of as a waste product or is given away to the local farmers as fertilizer, or if there is sufficient demand for the sludge, a nominal price is charged for it.

This tendency toward sludge digestion has led to separate sludge digestion and collection of the combustible gas for heating the sludge in the digestion tank, with consequent acceleration of the digestion time. In the absence of industrial wastes the average gas production is from 0.4 to 0.6 cu. ft. per capita per day for settled solids and from 0.6 to 0.8 cu. ft. for both settled solids and activated sludge. The gas has a heat value of 750 B. t. u. per cubic foot.

Dewatering of sludge still offers a serious problem in sewage disposal. Various mechanical devices such as vacuum filters or centrifugals have been used for dewatering sludge. The cost is still too high for general practical use. The goal toward which research in sewage disposal is now directed is the development of rapid sludge digestion at temperatures up to 125° F., concentration of solids before digestion and disposal of the digested sludge at the lowest possible cost.

In an article entitled, "*Sewage and Trade Waste Problems Solved by Chlorine*," *L. H. Enslow* sets forth the uses of chlorine in sewage treatment. Aside from its value as a sterilizing agent and deodorant, chlorine has found use in sewage disposal in protection of sewers against disintegration by sulphuric acid formed by the oxidation of hydrogen sulphide; in retarding biological activity in sewage and sewage effluents, thus diminishing the rate of oxygen depletion in waterways so that longer time is allowed for dilution and re-aeration to take effect. Chlorine has also been found useful as a precipitant for proteins in packinghouse and cannery wastes.

One of the more recent developments in the application of chlorine is the lime-chlorine process. In this process calcium hypochlorite is pro-

duced enroute to the point of application by the lime-chlorine mixture. The author, who is responsible for the development of this process, claims for it greater efficiency at lower costs than for chlorine used alone.

"*Petroleum Refinery Effluent Treatment*," is discussed by *John H. Hess*. Oil finds its way into the drainage system of a refinery in numerous ways and to separate this oil from the water is the most important problem in the treatment of refinery wastes. This is usually done in separators of the gravity type. The oil rises to the top and is removed by skimmers. Emulsions do not separate out in these gravity tanks. They must first be broken, a process which involves a special chemical problem for every type of refinery emulsion. The refinery also has some chemical wastes which are taken care of by dilution with large volumes of water. Acid sludges formed in the refining of oil are either burned as such or are treated with water and steam for the recovery of the oil and weak acid.

"*Useful Conversion of Refinery By-Products*," by *L. A. Mekler* tells of the progress being made in recovery of marketable products from material usually considered waste. Petroleum coke is finding commercial use as powdered fuel. Acid sludges are being treated for the recovery of the oil, acid and reaction products. The oil is usually sold as high grade fuel oil, the acid is either concentrated and re-used or is sold as weak acid; and the reaction products are burned in the refinery. Recently, however, considerable research is being done toward recovering the valuable sulphuric acids from these reaction products.

Refinery gases are treated to recover the liquid hydrocarbons, which find use as anti-knock agents, and also to recover propane and butane which are now being sold commercially as domestic fuel.

The processes employed in the treatment of gas house wastes are described by *A. R. Powell* in "*Disappearance of the Gas-House District.*" The chief source of waste from the manufacture of gas by coal carbonization is from the ammonia still. The liquor from this still contains 2 to 4% phenol, which if discharged into a stream from which the drinking supply is drawn, may produce disagreeable tasting chlorophenol products after the water is chlorinated. However, the ammonia-still liquors can be disposed of by being used as quenching water for the hot coke from the ovens; by extraction of the phenol by use of solvents, distillation, absorption or bacterial action; or by disposal into the sanitary sewage system of the community.

The waste from gas made in carburetted water-gas plants consists chiefly of tars and oils and the problem here is to separate these from the water before it goes into the stream. This is usually done in a gravity separator. Water-tar emulsions cause some difficulty, at times, and must be broken up either by centrifuging, distilling or hot settling.

In an article entitled, "*Putting Wood Waste to Use*," *C. A. Basore* enumer-

ates the various ways in which the waste product of the sawmill and factory are being utilized. Sawdust and shavings are burned without any further treatment, or in briquettes for power production. They are being distilled for recovery of valuable chemicals and charcoal and along with some of the coarser forms of sawmill waste are being used in manufacture of paper.

"*Disposal by Utilization in the Pulp Industry*," by *C. M. Baker* discusses the waste-disposal problem in paper and fiber board manufacture. The chief source of waste is in the "white water," which contains a large per cent of suspended solids and exerts only a small B. O. D. on the stream, and the sulphite liquor, which has a high organic content and high B. O. D.

The white-water problem has been satisfactorily solved by the re-circulation and substitution of this waste for fresh water whenever possible.

The sulphite-liquor problem offers much greater difficulties. This liquor contains 50 per cent of the dry weight of the original wood. Because of this fact much time and money has been spent on research with a view toward recovery of valuable products from sulphite liquors. No entirely satisfactory method has been discovered, but concentration of the liquor by evaporation is used in several places. The residue is converted into tanning extract or corebinder, and is used for briquetting coal.

Fermentation of the liquor into alcohol has also been tried unsuccessfully. Chemical precipitation with recovery of calcium sulphite, lignins, resins and other organic substances is suggested. These substances may be burned or may be further developed into marketable by-products.

Walter E. Hadley relates "*How a Textile Mill Purged Its Effluents.*" Bleach house wastes were successfully treated with hydrated lime and alum in a settling tank; sulphuric acid was used to neutralize the caustic waste from the mercerizing plant, after which it received alum treatment; waste from the dyehouse also responded to this treatment.

"*Amelioration of Packing-House Waste*," by *Anthony J. Fischer* describes briefly the treatment of these wastes with liquid chlorine to precipitate the protein matter. This method was developed by H. O. Halvorson and has been published and abstracted in the SEWAGE WORKS JOURNAL.

The dewatering, drying and use of activated sludge as a fertilizer is described by *C. K. Hooper* in, "*Profitable Fertilizer from City Sewage.*" The sludge contains 5.2 per cent nitrogen, 2.7 phosphoric acid and 0.3 potash. Approximately 3000 tons per year are produced and sold at Pasadena.

This issue of *Chemical and Metallurgical Engineering* contains, in addition to the papers abstracted above, articles by *R. D. MacLaurin* on "*Atmospheric Pollution*," *H. B. Meller* on "*Smoke Abatement*," *R. E. Hull* on "*Water for Chemical Use*," *John R. Baylis* on "*Quality in Public Water Supply*," *L. L. Hedgepeth* on "*The Use of Chlorinated Copperas in Water*

Purification," *G. J. Fink* on "*Alum and Aluminates in Water Treatment*," and numerous short articles on waste disposal, stream pollution and water purification by the editorial staff.

Modern Sewage Treatment Plant

BY ALBERT N. AERYNS

Municipal Sanitation, **2**, 426–427 (Sept., 1931)

ABSTRACTED BY E. HURWITZ

The Larchmont, N. Y., treatment plant is located in a strictly residential neighborhood and is designed to satisfy the aesthetic sense of the people of the community. It has a capacity of 770,000 g. p. d. and at present is treated 515,000 g. p. d. from a population of 5500 people.

The features of the plant are a screen chamber with 1-in. bar screen; 2 hopper-bottom sedimentation tanks with 4-hr. detention period, plus 1000 cu. ft. for sludge and scum; a chlorination chamber having a 20-min. contact period; 4 sludge digestion tanks; and 2 glass-covered sludge drying beds, providing an area of 0.5 sq. ft. per capita.

The plant is thoroughly disguised and camouflaged so as to give the appearance of a high grade florist shop and greenhouse. All tanks are built underground, covered and grassed or are housed. The entire structure is thoroughly ventilated to prevent odors.

Screenings Incinerator

BY M. W. TATLOCK

Municipal Sanitation, **2**, 428–430 (Sept., 1931)

ABSTRACTED BY E. HURWITZ

The incinerator at Dayton, Ohio is designed to burn screenings from the Dorr screens and from 4-in. bar racks at the pumping station as well as grease and skimmings from the detritus tanks. It is gas-fired, using as far as possible the gas from the Imhoff tanks supplemented, if necessary, by gas purchased from the local public service company. The ash from the incinerator is disposed of on the sludge dumps or for filling in low ground. The average operating temperature, 1750° F., is such that there is no odor nuisance from the stack.

The screenings are pressed and fed into the incinerator with an average moisture content of 64 per cent. About 2.31 cu. ft. of screenings are obtained per million gallon of sewage. The fuel cost was 32 cents per million gallons and the total cost of incineration for 1930 was 71 cents p. m. g. of sewage treated.

Dearborn Sewage Treatment Plant

BY MARK B. OWEN

Municipal Sanitation, **2**, 476–480 (October, 1931)

ABSTRACTED BY E. HURWITZ

Chemical and mechanical treatment of sewage will be employed at the new West Side Plant at Dearborn. The process consists of adding lime, ferric chloride, and paper pulp to the sewage, which is passed through a baffled mixing chamber and into a circular clarifier. The sewage then flows upward through a 3-in. magnetite bed, is chlorinated and discharged into the river. Sludge will be dewatered by Oliver filters.

It is planned to use the grit as an aid in disintegrating screenings and paper in a ball mill. Lime for the process will be obtained from the waste dump of the Prestolite Company. Paper will be salvaged from the city refuse, also tin cans and waste iron which will be used in making ferric chloride.

Preliminary experiments indicate a reduction of 86 per cent in suspended solids and 67 per cent in B. O. D. The Oliver filters are expected to dewater the sludge to a cake containing 60 to 65 per cent moisture.

Some Operation Results of Sewage Plants at Boonton

BY W. C. MALLALIEU

Municipal Sanitation, **2**, 496–498 (October, 1931)

ABSTRACTED BY E. HURWITZ

The Jersey City Sewage Disposal Plant, located near Boonton, N. J., was designed for a population of 200,000. The plant consists of bar racks with 2-in. openings; 12 sedimentation tanks with 1.0 m. g. capacity; 5 hopper bottomed digestion tanks, fitted with gas collectors, and with a sludge of 66,000 cu. ft.; 4 glass-covered drying beds with an area equivalent to 1.0 sq. ft. per capita; 2 acres of contact beds; 6 acres of sand filters; and chlorinating equipment consisting of Wallace and Tiernan solution-feed chlorinator and detention tanks of sufficient size to provide one-hour contact period.

Sewage reaching the plant has an average of 162 p. p. m. suspended solids. The sedimentation tanks remove an average of 79 per cent of these solids. After passing through the sand filter practically 100 per cent are removed. The effluent is clear, sparkling, and has a bacterial reduction of 98 per cent. Chlorination further reduces this to 99.999+ per cent.

New Sewage Treatment Plant Serves Grand Rapids

BY SAMUEL A. GREELEY

Municipal Sanitation, **2**, 377-378 (August, 1931)

ABSTRACTED BY E. HURWITZ

The new Grand Rapids, Mich., plant has a capacity of 32.5 m. g. d. and is built to serve a population of 250,000 people. At present the sewered population is estimated at 164,000 and the flow to the plant only 22.0 m. g. d.

Sewage flows into the plant through $1^3/_8$ in. hand-raked bar screens. It then passes through a grit chamber at a velocity of 1.0 ft. per second. The grit chamber has 5 channels and a flowing-through length of 60 ft. From the grit chamber the sewage flows to 4 primary settling tanks equipped with Dorr sludge-removal mechanism. These provide a detention period of $1^1/_2$ hours for a flow of 32.5 m. g. d. The settled sewage is discharged into the river.

Sludge is digested in 4 tanks having a total capacity of 380,000 cu. ft. or about 2.8 cu. ft. per capita. These tanks are equipped with gas collectors and Dorr mechanism for stirring A fifth sludge tank having a capacity of 344,000 cu. ft. is provided for storage. The sludge drying beds have a combined area of 190,000 sq. ft.

The plans for the completed plant include the installation of aeration units to treat the effluent from the primary settlers.

Ohio Conference on Sewage Treatment

Third Annual Report

Oct. 22-23, 1929

ABSTRACTED BY H. GLADYS SWOPE

The papers in this report were presented before the Ohio Conference on Sewage Treatment at the meeting held at Canton, October 22-23, 1929.

"Operating Results, Canton Sewage Treatment Plant," by Charles C. Hommon. The present plant, which was put in operation in the fall of 1926, is designed for a population of 135,000 and a sewage flow of 13.5 m. g. d. The plant consists of bar gratings, an incinerator for burning the screenings, grit chambers, Imhoff settling tanks, sewage pumping station, trickling filters (7 feet deep with blast furnace slag as a medium), secondary settling tanks, sludge pumping equipment, office and laboratory.

Average analyses for 1927–28–29 were as follows:

Average	1927 Raw	1927 Tank Eff.	1927 Filter Eff.	1928 Raw	1928 Tank Eff.	1928 Filter Eff.	1929 Raw	1929 Tank Eff.	1929 Filter Eff.
Flow, m. g. d.	7.0	...	....	7.6	...	....	9.7	...	....
Susp. solids	195	63	55	212	68	45	288	80	51
Diss. oxygen	...	....	6.7	...	...	5.4	...	...	5.4
5-day B. O. D.	187	114	23	175	104	21	202	101	25

Sludge is disposed of on a municipal farm which is run as part of the sewage disposal plant.

"The Oxygen Demand Test and Its Relation to Sewage Treatment and Stream Pollution," by C. B. Hoover. The author has reiterated the pitfalls of the oxygen demand test, emphasizing proper dilution and diluting water and the sealing of bottles. At the Columbus sewage treatment plant laboratory it was found that the 5-day B. O. D. at 20° C. was $1^1/_3$ times that of the 24-hour demand at 37° C. for raw sewage. Examples are given to show the effect of the oxygen demand of raw sewage on various stream flows. Discussions by R. D. Scott of the Ohio Dept. of Health and Emery J. Theriault of the U. S. Public Health Service dealt primarily with the proper dilution water.

"Procedure Recommended for the B. O. D. Test by the Ohio Department of Health, February 13, 1930." F. H. Waring, Chief Eng. The points which differ from those given in Standard Methods of Water-Analysis for 1925 are: distilled water as diluent; if sample is alkaline to brom-thymol blue and not alkaline to phenolphthalein no adjustment is made, if alkaline to phenolphthalein hydrochloric acid is added to neutral point, and if acid to brom-thymol blue sodium hydroxide is added to neutral point; initial dissolved oxygen is determined if concentration of diluted sample exceeds 4 per cent.

"Operating the Small Sewage Treatment Works," by Floyd G. Browne. Most of the sewage treatment plants in Ohio are small and little attention is given to their proper operation. A discussion by Bruce M. McDill of the Ohio Dept. of Health emphasizes the need of proper operation of these small plants. The Health department has arranged for a part-time technical supervisor so that these plants may be visited three or four times each month.

"The Salem Sewage Treatment Plant," by F. S. Barckhoff. The new sewage treatment plant was put in operation in March, 1929, and serves a population of 11,000. It is of the activated-sludge type comprising a mechanically operated Dorr screen, a bar screen and an incinerator for burning screenings; grit removal is accomplished in an aerated (filtros plates) influent channel, $22^1/_2$ feet long and 3 feet wide, to the primary clarifiers; primary sedimentation in Dorr traction clarifiers; three aera-

tion tanks, 200 feet long, 10 feet wide and water depth of 9 feet, detention period of 6 hours; two secondary Dorr clarifiers; and chlorination of the effluent from these tanks.

Sludge from the primary tanks is digested in separate tanks fitted with gas collectors. Activated sludge from secondary clarifiers is returned to the mixing channel. Excess activated sludge may be disposed of by any or all of four ways: sand filters, returned to primary clarifiers, separate digestion, or pumped to sludge storage tank to settle. Digested sludge is run onto sand filters.

Supernatant liquor from the digestion tanks is returned to primary clarifiers or to sludge storage tank. Supernatant from sludge storage is run onto sand filters, to aerators or to primary clarifiers.

The gas collected is used in heating the plant.

"Sewage Disposal Litigation," by F. D. Stewart. It is far better for a community to treat its sewage and for industrial plants to purify their wastes than to pay heavy damage suits. Complete operating records of a treatment plant should be kept so that this may be used as evidence in court. A technical supervisor should be in charge of the plant.

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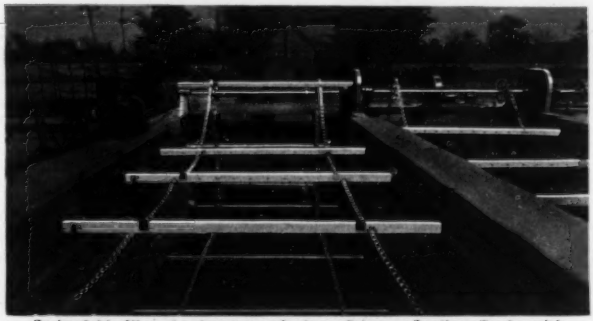

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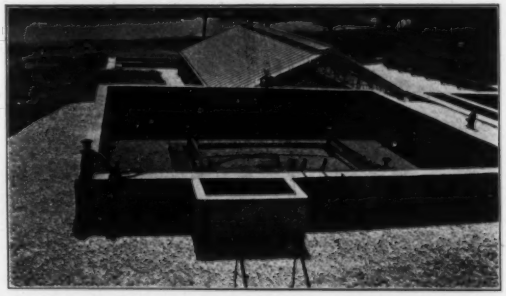

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